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DESIGN/PRODUCTION INTEGRATION
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Proceedings: Building the Ships and
Boats of 2010 - The Way Forward**

**U.S. DEPARTMENT OF THE NAVY
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PAPER COSTS MONEY

An Oral Presentation
to the 1991 Ship Production Symposium
Society of Naval Architects and Marine Engineers

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by

Maurice R. Caskey

Vice President, Engineering
Jered Brown Brothers Inc.
Member

PAPER COSTS MONEY

by
Maurice R. Caskey

The title of this presentation is "Paper Costs Money." It could also be entitled "Paper Costs Time" or "Paper Causes Inconvenience." We all know, and talk about, the cost of data which are submitted to the government under shipbuilding contracts.

First, I would like to establish some definitions for today's presentation. How many of you know the dreaded acronym "CDRL"? Some people say they are submitting a CDRL." Others say they're submitting "data" or "reports"; purists say "technical documentation."

Today's discussion will focus on the data which were required under recent U.S. Navy shipbuilding contracts. It would be nice to examine vessels being built for several commercial owners, but the field is rather limited. And, naval ships built to either commercial rules or military requirements comprise the preponderance of contemporaneous activities in the industry. Perhaps it is tutorial, but the following terms will be used today for common understanding of Navy data requirements:

CDRL, the Contract Data Requirements List cited as a contract section J exhibit by each Navy contract. The CDRL may be in two or more separate parts, which are listed as exhibits "A," "B," "C," etc. This document invokes all of the data submission requirements on the prime contractor. A CDRL is printed on a DD Form 1423.

ELIN, the Exhibit Line Item Number for each specific data submission requirement of the CDRL.

DID, Data Item Descriptions are invoked by the DD1423, block 4, for each of the ELINs. The requirements of the ELIN may modify the DID or provide amplifying instructions. The DID identifies requirements such as content, format, etc. for a specific report.

Technical documentation, report, or data submission, the data which are submitted to the customer in compliance with a specific DID under a specific ELIN of each exhibit of the CDRL.

SDRL, a Subcontract Data Requirements List invoked by a shipbuilder on a subcontractor. This document goes by a number of different names, based on the custom of the shipbuilder. It serves the shipbuilder as a vehicle to require data be submitted Just as the CDRL serves the Navy.

Now for a-few more terms... which of these do you associate with a CDRL?. "Expensive." "Cost effective." "A waste of time." "Helpful." "Irritant" "Expediter."

It probably takes little imagination to guess which set of terms you picked. Our challenge in the marine industry is to determine how to move towards the other set of words. The money available, to buy ships is diminishing; we must come up with a way to buy more steel for the money available.

One lead ship bid concluded that 20% of the non-recurring cost would be related to data submissions. That was the ship designer/ship builder's cost. It did not consider the added costs of data which were paid for in the material purchased for ship construction. The latter cost becomes buried in the recurring cost lines.

In fact, data costs are incurred...and paid...at several levels of program funding. The shipbuilder sees basic construction cost. A Navy project sees many other cost elements which include data definition, handling, evaluation, and follow-up action.

A typical requirement for a report will result in various costs at a variety of activities for each ELIN:

- Navy prepares the input for requirements to be incorporated in the CDRL which will be included in the 'request for proposal and subsequent contract (typically cost for NAVSEA technical code labor)

- 'Bidding shipbuilders evaluate the CDRL's requirements, include details in the proposal for the contract (labor charged to Bid & Proposal (B&P) which is then included in general and administrative (G&A) rates)

- Shipbuilders identify data to be included in subcontractor estimates; subcontractors evaluate requirements and bid on hardware (labor charged to each subcontractor's B&P which eventually impacts the cost of purchased material)

- Navy evaluates the bids (the more data required, the more complex the evaluation; this influences the labor and time for the evaluation and selection process)

- Winning shipbuilder plans its own data submissions to meet the CDRL; prepares SDRLs for inclusion in purchase orders (POs) to collect needed inputs from subcontractors (non-recurring direct labor, G&A and overhead <O/H>)

- Subcontractors prepare reports required by the SDRL (direct, O/H and G&A labor and other costs such as

capital equipment, reproduction, etc.: these costs are often seen by shipbuilders as recurring material cost>

- Shipbuilder evaluates subcontractor data submissions; correspond to obtain updates and corrections (direct, G&A and O/H labor>

- Shipbuilder prepares technical documentation and other-data submissions required by the CDRL <more-direct, G&A and O/H labor and other costs)

- Navy evaluates shipbuilder data submissions; they: correspond to obtain updates and corrections; this cost- is in direct proportion to the distribution list for each ELIN (labor at various Navy offices and costs for a: number of "highway helper" contracts)

- Shipbuilder responds to the Navy comments, often involving passing those comments back to-the subcontractor (added direct, G&A and O/H-Cost)

- Various Navy offices (and/or "highway helpers") file, retrieve, dispose of, and otherwise handle the various reports; this cost is also in direct proportion to the distribution list for each ELIN (more government program costs)

- Repeat the entire cycle for each recurring report.

Each submission of each report required by each ELIN means a number of people handle the paper. Each person who is involved adds labor cost to the project. While many shipbuilders have the equipment and people to produce technical manuals, prepare microfilm copies of drawings, or take other actions to meet the specific requirements of a DID and DD1423 for the ELIN, many of the subcontractors do not. In either case, the costs appear as capital equipment which is included in the O/H rates, other direct cost <ODC>, and direct or indirect labor.

And even more troublesome, the comment or approval cycle for technical documentation can add an extended period of time to the ship's design and/or construction period. It also adds to the material lead time for new or modified hardware procured for any ship of a class.

Some ELINs state approval is required. If the shipbuilder or subcontractor proceeds prior to receiving approval, it does so at its own risk the comments may cause some significant change resulting in rework of the design or hardware. In some cases, the CDRL gives a specific time period to allow for approval; in others it does not. How long should the shipbuilder wait? And the subcontractor, who has submitted technical documentation via the shipbuilder, must wait even longer. In

the end, both shipbuilders and subcontractors assume the comments will not be extremely disruptive...and proceed.

Next, consider the ELIN which does not require approval. And, 45 days later the Navy's letter arrives with significant comments. What happens then? Should the shipbuilder or subcontractor have proceeded, and was it "at risk"? Waiting for comments which are well within the reviewer's purview slows the product ion cycle, not waiting carries an inherent cost risk. Both options are bad for shipbuilding.

In the final analysis, waiting for comments or approval may depend on the nature of the data item.

What are these data items? A detailed examination of one CDRL, issued under contract N00024-82-C-2121 for MCM-1, revealed an interesting breakdown. But first, some definitions of the categories arbitrarily used for the evaluation (ELIN, title and subtitle provided for each example > :

DELDOC - data submission associated with ship delivery; example: A069, "Electric Accounting Machine Card/Listing, Outfitting Material; Stock Record Cards Afloat <SRCA>, NAVSUP 1114."

DESREVtechnical documentation for review of ship (or hardware component> designs; example: A042, " Report , Reliability and Maintainability Allocations, Assessments, and Analysis; RMAAA, Deratlng Criteria, and Stress Analysis-Report."

HIST - technical documentation with provides a history of the ship's construction; example: A142, "Report, Inclining Experiment (Prellninary [slc] and Final); Inclining Experiment Report."

MAINT - technical documentation which is required for proper maintenance of the ship; example: A099, "Manual, Technical, Preliminary; Preliminary Technical Manual."

MGMT - technical documentation, financial data, schedules and other data submissions which allow the Navy to monitor and manage ship design and construction program; example: A199, "Cost/Schedule Status Report <CSSR>; Cost/Schedule Status Report."

OPNL - technical documentation which is required for proper operation of the ship; example: A101, " Book, Damage Control, All Ships; Damage Control Book."

PROV - technical documentation which is required to provision the ship, both on-board spares and shore-based

logistics: example: A055, "Logistic Support Analysis (LSAR) Data; Logistic Support Analysis Record (LSAR)."

SPCL - requests, reports, and other data submissions which are required on an as-the-need-occurs basis; example: A006, "Proposals, Engineering Change; ECP's and NECP's."

TEST - technical documentation which reports the results of shipboard or hardware component testing; example: A116, "Report, Ship Trial ; Report of Builder's Trial."

TSTPLN - technical documentation which provides planning and procedures for the conduct of shipboard and hardware testing; example: A179, "Procedures, Test; First Article, (Pre-production) Degaussing Equipment."

TRNG - data and reports associated with the training program for the ship's crew; example: B013, "Instructor/Lesson Guides - Training Courses; MCM Ship Degaussing System."

Some assumptions were used for the analysis to "normalize" the results to be representative of a generic ship contract:

Time span for contract - three years, or 12 quarters, or 36 months

POs requiring technical data - 100 hardware items

Hardware items requiring shock and vibration. qualification - 60 by test or extension

Hardware items requiring high impact (HI) shock & vibration testing - 30 (both grades A and B HI shock>

Approval cycle - reports and technical documentation will each require one comment/resubmission cycle to obtain approval ; periodic reports will not require any resubmissions.

Within these categories and following the assumptions, the various ELINs of the CDRL were examined. It was first noted the DD1423 often requires various reports, sometimes with different numbers of copies to differing distribution lists for those reports. Thus, it is necessary to examine the number of items of data, as well as the number of ELINs.

The CDRL for the MCM-1 includes 208 ELINs in Exhibit A (e.g., numbered A001 through A200) plus 23 ELINs in Exhibit B (e.g., numbered B001 through B023>. Of these, 14 ELINs are not used, leaving a total of 217 separate requirements. Some of the ELINs include multiple items, as noted above; thus, there are a total of 278 Exhibit A items and 21 Exhibit B items.

The various data items for MCM-1 were categorized as follows
<Note: four ELINs, due to their multiple items, were categorized in more than one category.):

CATEGORY	ELINs	ITEMS	APPROVAL REQUIRED	% REQUIRE APPROVAL
DELDOC	13	13	1	7.7
DESREV	36	58	26	44.8
HIST	26	37	7	18.9
MAINT		39	14	35.9
MGMT	13	49	13	26.5
OPNL	7	15	12	
PROV	13	12	7	53.8
SPCL	11	11	8	72.7
TEST		19	3	15.8
TRNG	19	21	19	90.5
<u>TSTPLN</u>	<u>24</u>	<u>24</u>	<u>12</u>	
Total	221	299	122	40.8

It might be noted that 41% of the 299 items of data required Navy approval. This has a serious implication for the shipbuilder's schedule.

in order to measure the true cost and schedule impact of the various data items on the shipbuilder and the Navy, it is necessary to determine how many times they are submitted. The Navy's impact is also driven by the number of copies made available (as required by the ELIN's distribution list>. Copies go to a number of different commands and codes within commands. For this analysis, we can use standard explanations based on Appendix 1 to Exhibit A, "General DD Form 1423 Glossary" :

DISTRIBUTION - the number of addressees to receive a copy of each submission of a particular data item: example: ELIN A042 requires 4 which are PMS 303, SEA 05MR, SUPSHIP, and SEA 56Z14.

REGULAR COPIES - the total number of regular copies to be forwarded to all addressees to meet the requirement for each submission of a particular data item; example: ELIN A179 requires 1 copy each be distributed to SEA 56214 and SUPSHIP, and 3 copies be distributed to PMS 303 for a total of 5 regular copies.

REPRODUCIBLE COPIES - the total number of reproducible copies to be forwarded to the designated addressees to meet the requirement for each submission of a particular data item: example: ELIN A142 requires 1 regular copy be distributed to the ship, 2 copies to SUPSHIP, and 3 copies to PMS 303; in addition, SEA 55W2 is to receive 1 reproducible copy.

TOTAL SUBMITS - the total number of submissions required for a particular data item based upon the assumptions described earlier; example: ELIN All6 has a designated frequency of "ONE/R", with a required first submittal 30 days after completion of builder's trial with subsequent submittal "R/ASR"; it is assumed one subsequent submittal will be required, and there is one builder's trial per ship; thus the total number of submissions for this item is 2 per ship.

An analysis of the requirements, by category, of each of the items compared to the distribution requirements, the frequency of submission, and the number of copies required, reveals the following theoretical number of submissions (Note: This is a "theoretical number" of submissions, it does not represent the actual submissions made during the shipbuilding program.):

CATEGORY	DISTRIBUTION	REGULAR COPIES	REPRODUCIBLE COPIES	TOTAL SUBMITTALS
DELD	42	59		7 + 63 per ship
DESREV	224	408	23	220 + 3 per ship
HIST	143	237	30	20 + 84 per ship
MAINT	196	251	37	226 + 12 per ship
MGMT	154	297	8	506 + 225 per ship
OPNL	77	114	19	139 + 2 per ship
PROV	29	41	6	59 + 1 per ship
SPCL	42	62	0	not estimated
TEST	68	124	5	179 + 63 per ship
TRNG	39	80	0	42 + 2 per ship
<u>TSTPLN</u>	<u>79</u>	<u>156</u>	<u>1</u>	<u>283 + 25 Per ship</u>
Totals	1,093	1,829	133	1,681 + 480 per ship

It may be interesting to note that a single submission in response to each item would result in 1,093 envelopes in the mail with 1,962 regular and reproducible copies. But, that isn't an accurate picture. It is estimated a total of 1,681 scheduled submissions would be required over the period of contract performance plus another 480 submissions for each ship built. Almost all of those submissions require one or more copies to multiple addressees.

With these data, we can start to draw some conclusions about what drives the costs. Many of the submissions are in what might be considered the oversight categories of design review, management and special categories. The test program includes the test and test planning categories. Integrated logistic support (ILS) comprises the maintenance, provisioning and training categories. The data needed by the ship's crew certainly include much of the ILS plus the delivery documentation, history and operational categories.

The Navy undertook a major revision of the CDRL for the MCM-9 contract (e.g., N00024-88-C-2229), which includes options for

the MCM-10, 11, 12, 13, and 14. One of the stated purposes of the revision was to reduce the requirements for data. The CDRL was reduced to a single exhibit, and includes ELINs A001 through A211, with a total of 279 ELINs. Those requirements are subdivided further into a total of 304 items, and three ELINs are not used.

An analysis of the ELINs of the MCM-9 CDRL for categorization similar to that done for the ELINs of the MCM-1 CDRL produces the following <number in parentheses is the delta between MCM-1 and MCM-9):

CATEGORY	ELINs	ITEMS	APPROVAL REQUIRED	% REQUIRE APPROVAL
DELDOC	12 (1)	12 (-1)	1 (0)	8.3
DESREV	57 (+21)	62 (+4)	30 (+4)	48.4
HIST	31 (+5)	38 (+1)	7 (0)	18.4
MAINT	41 (+28)	42 (+3)	18 (+4)	42.9
MGMT	50 (+12)	64 (+15)	21 (+8)	32.8
OPNL	14 (+7)	14 (-1)	12 (0)	85.7
PROV	12 (-1)	13 (0)	7 (0)	53.8
SPCL	12 (+1)	12 (+1)	8 (0)	66.6
TEST	21 (+2)	21 (+2)	3 (0)	14.3
TRNG	0 (-21)	0 (-21)	0 (-19)	
TSTPLN	26 (+2)	26 (+2)	13 (+1)	5 0
Total	276 (+55)	304 (+5)	120 (-2)	39.5

While the above table indicates a significant growth in ELINs, the total number of data items grew by only five; and, the number of ELINs requiring approval dropped by two, the percentage dropped about 1%. It can be seen clearly that the growth occurred in the oversight categories, while the training category was eliminated.

Further analysis of the theoretical number of submissions for the MCM-9 contract reveals the following (number in parentheses is the delta between MCM-1 and MCM-9):

CATEGORY	DISTRIBUTION	REGULAR COPIES	REPRODUCIBLE COPIES	TOTAL SUBMITTALS
DELDOC	39 (-3)	56 (-3)	3 (-1)	29 + 63 per ship
DESREV	253 (+29)	464 (+56)	27 (+4)	239 + 6 per ship
HIST	136 (-7)	235 (-2)	31 (+1)	23 + 85 per ship
MAINT	205 (+9)	258 (+8)	42 (+5)	425 + 12 per ship
MGMT	187 (+33)	358 (+61)	8 (0)	904 + 223 per ship
OPNL	72 (-5)	117 (+3)	16 (-3)	135 + 2 per ship
PROV	29 (0)	41 (0)	6 (0)	125 + 1 per ship
SPCL	39 (-3)	72 (+10)	1 (+1)	not estimated
TEST	77 (+9)	147 (+23)	6 (+1)	196 + 244 per ship
TRNG	0 (-39)	0 (-80)	0 (0)	0
TSTPLN	86 (+7)	169 (+13)	2 (+1)	285 + 25 Per ship
Totals	1,123 (+26)	1,917 (+89)	142 (+9)	2,361 + 661 per ship

It is again interesting to note that a single submission in response to each item would result in 1,123 envelopes in the mail with 2,059 regular and reproducible copies. Again, that isn't an accurate picture. It is estimated a theoretical total of 2,361 scheduled submissions would be required over the period of contract performance plus another 661 submissions for each of the 6 ships built (including options), a combined total of 6,327 submissions!

The increase in submissions is disproportionate <i.e., growth of 680 scheduled submissions plus 181 submissions per ship) to the increase in ELINs and items. This is because the submission frequency requirements changed for some ELINs, and the entire body of training data was replaced numerically by management data.

Because MCM-9 is a follow-ship contract, the need for design review, maintenance, operational, provisioning, test, and test planning submissions was probably reduced. However, each hardware change worked to offset that reduction. And, if another shipbuilder which had not previously built a ship of this class wanted to enter the competition, it would be faced with almost the entire set of submissions.

Please do not think by this time the author is picking on the MCM program or its shipbuilders. A similar examination of the CDRL for the T-AO 194 and 196 (e.g., contract N00024-85-C-2131) shows a similar set of requirements in the design review, management and ILS areas. What is missing are many of the test and certification data expected for a warship with its attendant survivability requirements. Other CDRLs for ships such as the CG-47 class follow ships, DDG-51, LHD-2, and similar warship programs include requirements which are quite comparable to the MCM-1 class CDRLs.

How do these requirements relate to the price paid for shipbuilding products? Examination of a 1990-91 bid for a shipyard product produces the following division of price:

- 17.2% One-time costs - design, ILS, and all data
(including those data related to production>
- 73.7% Recurring costs - procurement of material and
manufacture of the product
- 9.1% Tests & demonstrations - test program, on-board
crew training, and associated activities.

The line item structure of this particular contract makes it possible to identify the price for the system engineering and design, the drawings and calculations, the ILS analyses and training preparation, and other technical tasks, as well as the program management tasks, all of which are required by the contract. Those prices, which are included in the one-time

cost, can be segregated from the cost of the data submissions per the CDRL. Such submissions account for 24.6% of the price of those contract line items in the "one-time cost" category, and exceed over 4% of the overall price of the bid. Further, the cost of the data included in the procured material prices, combined with the effect of preparing data submissions on G&A and O/H rates (which are applied against all direct costs), would easily raise the data submission impact on the overall contract price to high in the 5-10% range.

It is not possible for this author to examine costs to the government in terms of employee payroll and subcontract help. As is the case with ship designs, a certain level of effort is required to oversee the design and construction of a modern warship or commercial vessel. Design reviews, program progress reports, quality inspections, and witnessing tests are all activities which protect the government's interests. These activities often involve subcontractors as well as the shipbuilders.

It would be interesting if someone with access to the necessary data could prepare a follow-up paper to this one to assess the percentage of the government's programmatic costs which is directly attributable to data definition, receipt, handling, evaluation and follow-up action. It is a safe bet that it is at least as high as the 25% of one-time cost indicated above.

An example at the other end of the spectrum is in order. Conversations with representatives of Astilleros Espanoles SA, the Spanish commercial shipyard, concentrated on data submitted to commercial owners. European commercial shipbuilding requires adherence to governmental regulatory body and classification society regulations and rules, just as occurs in the United States with the U.S. Coast Guard and American Bureau of Shipping.

The ship designer must submit to the owner and the classification society about 40 to 50 plans. These plans are for the approval of the design. They roughly correspond to the U.S. Navy's selected record plans. These same plans are provided to the ship to reflect her as-built condition.

In addition to the plans, equipment arrangements and equipment technical manuals are provided. The manuals, needless to say, do not meet the rather elaborate requirements of today's technical manual contract requirements (TMCRs). Most of the documentation is being delivered in a digital format, with a growing use of laser disks.

It is recognized that a naval warship has ILS, survivability and other requirements which are different from those of a commercial vessel. The designs for warships are typically quite unique, one from the other; and, warships have an

extensive test program to verify proper hardware design and manufacture. In addition, the shipbuilder cannot procure certain outfitting items such as the weapons suite. Thus, there is an increased need for management dialogue between the shipbuilder and the customer. Often times, this increased information flow will involve subcontractors.

Here, then, are seven recommendations for arriving at a logical point somewhere between the extremes of commercial technical documentation requirements and today's "standard" Navy requirements.

First, examine carefully and realistically the results of each data submission. Do reviews really result in design changes? Are data just filed away without action? What happens to each copy on the distribution list, does each addressee need a copy (or copies) of each and every submission of all reports per a particular ELIN? What is the pay-back for the price the government (and we taxpayers) expends on each data item...is it justified economically?

When the CDRL is assembled for the next Navy contract, do not include any ELIN for which there is not adequate justification. This will require a very hard-line approach by the project office; and will, undoubtedly, cause more than a few codes, commands and offices to complain bitterly.

Second, trim the distribution list for each ELIN to the absolute minimum. It costs time and labor to reproduce and distribute multiple copies to multiple addressees. Nonetheless, it probably is cost effective to have the originator make all necessary copies at one time. If this is true, it would also make sense for subcontractors to submit data directly to the Navy.

Third, reduce the frequency of submission of recurring reports to that which is absolutely essential. Make monthly reports quarterly, quarterly reports semi-annual, and so forth. This could cut the total number of submissions in half. Further, much of the cost to prepare management reports is incurred under O/H and G&A accounts, and it would help reduce rates.

The Navy can protect the government's interests by on-site activities. The offices of the supervisors of shipbuilding could have people sit in on the design reviews as the design evolves. This would allow real-time feedback.

The Navy should implement the management principle of "MBWA" for the its oversight of the shipbuilders and their principal subcontractors. "Management by walking around" and seeing what is under test, under construction, and being considered at the design reviews. There would need to be a real effort to eliminate some of the adversary attitudes between the government and prime contractor people, and Washington would

need to develop more trust in the people in the field, but It can be done.

Fourth, make more use of magnetic media and digital formats. Standard computer aided design (CAD) systems today can produce both magnetic media and laser disks for drawings; word processors can produce output in a variety of digital formats. The labor cost savings to provide copies in digital format over paper copy reproduction will more than offset the added cost of materials. An added benefit is the space saving feature of the digital format. Paper copies are needed only for record purposes, only for a selected number of items of technical documentation or financial data, and then to reflect the as-built condition.

Fifth, shipbuilders use a more standardized format to prepare SDRLs. A SDRL would define specific data needed by the shipbuilder, such as a loose parts list. In addition, it would incorporate the exact DD1423 language for applicable ELINs from the CDRL and invoke the same DIDs, only adjusting the number of copies to be submitted to call for the shipbuilder to receive an appropriate number of copies for its own internal use and review. If this were to be done, subcontractors could submit data to the shipbuilder and the Navy concurrently. The approval period for parallel submissions would apply to all of the subcontractors' data, just as to a shipbuilder's data.

Sixth, incorporate a clause in each prime contract that any and all comments must be provided on a data submission not more than 30 calendar days after receipt by the Navy. Approval would be assumed automatically if comments were not received within that time period. Subcontracts would include a similar clause allowing the shipbuilder a total of 15 days for handling the outgoing submission to the Navy and passing the Navy's comments or approval back to the subcontractor.

Seventh, allow only one set of comments on a particular data submission or report. We can all tell horror stories of the technical manual which never does get a "clean" review because each new reader reads with his or her own interpretation of the TMCR, or discovers a previously unknown deficiency.

If this suggestion, along with the parallel submission suggestion above, were to be implemented, subcontractors could incorporate all of the comments at one time, instead of serially, with two resubmittals, as is done now. This would have the effect of saving considerable time as well as cost.

A final observation, the "one set of comments" rule, combined with a "30 day" rule, would enforce discipline on each report's reviewers. If the technical documentation were to be revealed as fatally flawed sometime after the 30 day period allowed for review, or after the subcontractor or shipbuilder

resubmits the report, a simple unilateral change in accordance with the "Changes" clause of the contract could be issued by the contracting officer to provide for yet another submission. If there are any contracting officers in today's audience, I can surmise how you are reacting to this idea!

It is possible, with some real effort on the part of the Navy (as the customer>, shipbuilders and subcontractors, to reduce significantly the cost of technical data and management reports. A goal of 10% of the total program cost (not just basic construction cost) is realistic, and probably achievable. If each of the present Navy ship programs were to have such a reduction, it would be possible to add one more low-mix ship to each year's construction schedule. Is there anyone in the Society today who would not like to see that?



A Return to Merchant Ship Construction: The International Impact of the NSRP and American Technology

IIA-1

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SUMMARY

In the mid-eighties, the state-owned shipbuilders of Spain were suffering from many typical shipyard problems, making them uncompetitive. After making a strong reentry in the commercial shipbuilding market, they engaged in a process of reorganization of the entire production system according to modern Japanese practice. The goal was to become competitive with the world's best. The know-how was acquired via cooperative agreements with leading Japanese shipbuilders as well as through the use of American consultants and NSRP-related literature. A comprehensive technological improvement plan has been launched and the initial results are very promising.

INTRODUCTION

In the early and mid-seventies Spain was the third largest shipbuilding nation in the world, in terms of both orderbook and production, ranking only after Japan and Sweden. About half of the large and medium yards were grouped in a state-owned organization, the rest being privately owned. Small shipyards were, in general, privately owned. Export orders comprised the majority of the orderbook. The general mood was optimistic, and shipbuilding was seen as one of the most promising locomotives for the industrial development of the country. There were plans for heavy investment in new facilities, hoping to eventually become the rival of Japan. The industry was competitive on the basis of abundant, cheap labor and a long shipbuilding tradition.

The 1973 oil crisis left the world's shipbuilding industry in disarray as orders almost disappeared. Some countries began to take measures to readapt production capacities and methods to the new environment, but unfortunately Spain was not one of them. See Fig.1. Full speed production continued until the end of the decade, thanks to a very large initial orderbook, long building periods and domestic fleet building programs. A brief market recovery in the late seventies further delayed the realization of how deep the crisis was to be.

SPANISH STATE-OWNED YARDS DELIVERIES 1975-90

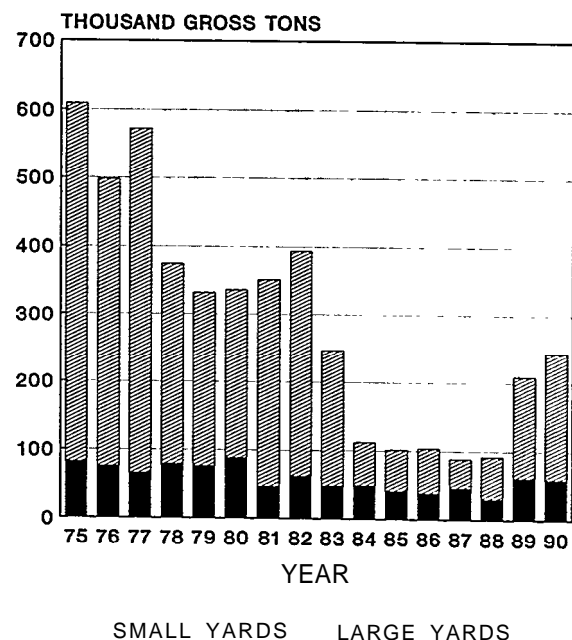


Fig.1

In the early eighties, just after the second oil crisis, disaster finally struck and the Spanish shipbuilding industry found itself hopelessly uncompetitive against new low-cost producers like Korea and some East European countries. Orders disappeared and soon our shipyards were nearly empty. The fall was particularly hard in the case of the large shipyards, all of which eventually became part of a state-owned group in an attempt to save them. Most observers expected the demise of the Spanish shipbuilding industry, following the path of Sweden's several years earlier.

This presentation is about the process of recovery and describes how the state-owned shipyards of Spain managed to re-enter the market. We will specifically concentrate on the way in which our group changed its production system, adopting an advanced manufacturing organization capable of delivering, by the mid-nineties, a performance close to that of the world's shipbuilding leaders.

PRODUCTIVITY IMPROVEMENTS IN THE SEVENTIES

As indicated above, the competitiveness of our yards was based on low-cost production. Productivity, while important, was not one of the most critical factors. High production rates were achieved by the use of large numbers of workers. However, some shipyard managers knew that Spain would lose its low-cost advantage sooner or later, due to the inevitable incorporation of the country into the group of industrialized nations. This had happened before to Japan and had been overcome by the adoption of astonishingly efficient production techniques. Therefore, isolated measures began to be taken to follow the Japanese example, as some major shipyards in Spain attempted to incorporate the latest Japanese shipbuilding technologies. They hired a leading Japanese shipbuilder to analyze their construction processes and give recommendations for improvement. There were learning trips to Japan by senior Spanish executives, and Japanese experts were stationed in the Spanish yards to monitor the application of their recommendations and give advice on daily operations. The late seventies and early eighties saw the progressive implementation

of some advanced Japanese techniques at leading Spanish shipyards, with large gains in production efficiency. Unfortunately, not all shipyards were that progressive and many kept relying on old methods.

PRODUCTIVITY IMPROVEMENTS (OR LACK THEREOF) IN THE EIGHTIES

The years after the second oil shock were very negative for productivity improvements. The numerous workers of past days were now a heavy liability because Spanish laws made any reduction in the labour force via layoffs difficult and expensive. As the orderbook collapsed, shipyards were left with large payrolls, and management had to concentrate efforts on workforce reduction and financial problems. Most shipyard growth, in the fifties and sixties, took place in remote areas of Spain for the purpose of promoting industrialization. In such regions there were no alternate employment opportunities, and the general recession made it difficult for people to find jobs elsewhere. To lure people away from shipyards, the Government sponsored generous severance and early retirement schemes. As a result, many of the best and most experienced people left the industry, but too many others preferred to stay. The labor reduction efforts continue to this day. The overall reduction has been dramatic, from over 35,000 laborers in 1975 to just under 9,000 today. See Fig.2.

In this climate, labor was unsupportive of attempts to improve productivity, as it could further reduce the number of those needed in the future. However, a renewed effort was made to adopt the latest Japanese techniques in the large shipyards. A new agreement was signed in the mid-eighties with a major Japanese shipbuilder for this purpose. The past pattern of trips to and from Japan started again. This time nearly 200 AESA employees travelled to see the Japanese yards. This included more than just top management. Union leaders and senior shop foremen were also engaged in the trips. The program lasted two years and much was learned. However, it was hard to see any measurable effect in our production efficiency. Orderbooks were so meager and available labor force was so large that

SPANISH STATE-OWNED YARDS LABOUR FORCE 1975-90

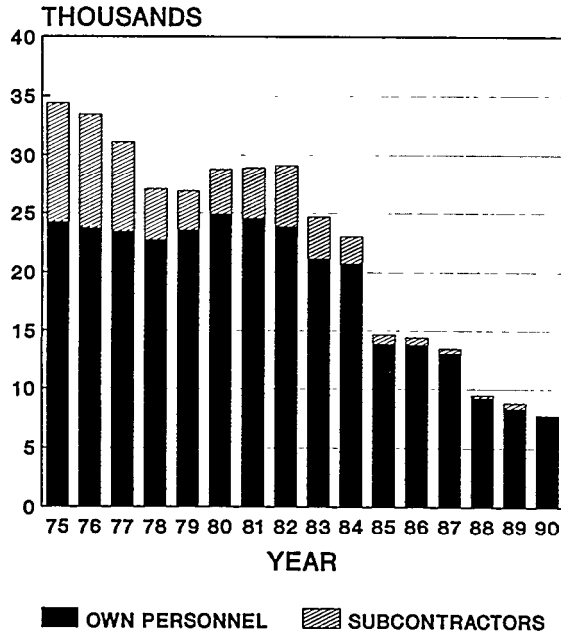


Fig.2

productivity fell to the lowest historical values in 1985-87. See Fig.3.

A definite change took place in 1987, when senior management launched a strong commercial effort to fill-up the building berths and docks. A large specialized salesforce was trained and sent overseas to canvass the world for the few orders shipowners were placing. Marketing was based on sophisticated media and image campaigns, plus untiring travel for contacts with brokers and customers. Also very important were financial engineering teams that were brought in to prepare competitive offers, making the best of Spain's currency, exchange rates and credit schemes. Last but not least, Government support, both political and financial, was secured. The effort paid off; in less than one year we had obtained substantial orders from first class international owners. Taking advantage of a slightly improved market we pursued our efforts and by 1989 we had again a full orderbook.

1. Some details of how this commercial success was achieved were presented in a restricted seminar for students of the University of Michigan. March 27/28, 1991.

PRODUCTIVITY HISTORY SPANISH STATE-OWNED YARDS

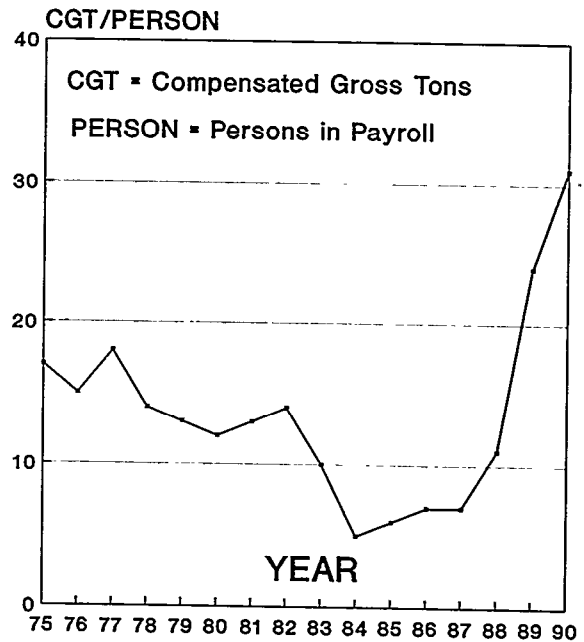


Fig.3

In parallel with this commercial campaign, all our factories were brought up to full capacity production. In 1988-89 we restarted large-scale production in our five ship-oriented newbuilding yards and one specialized offshore artifact yard. After the long years of subactivity, our productivity grew rapidly and soon reached levels similar or better than the best before the crisis. We gave a large share of credit for this to the collaboration with the Japanese. However, as we gained speed, our machinery began to rattle. We were very near our practical limits and we were getting good results by working very hard.

THE PRODUCTIVITY CHALLENGE OF THE NINETIES

While we were enduring the years of crisis, our Japanese friends and competitors had kept improving their productivity at an almost incredible pace of 5 to 10% annual cumulative rates. During the eighties, leading Japanese yards had cut in half production manhours for a given ship. We realized that, in spite of our relative improvements in the last years of the decade, we were still very far from the productivity of the world's best. We could not expect to be competitive unless there was strong demand and

good prices. At the same time, new trends in the European Economic Community pointed towards the end of all state support for shipbuilding. For strategic reasons, it was obvious that a united Europe would need efficient shipyards, but not necessarily those located in Spain. To ensure our own long-term survival, we needed to further improve productivity until achieving Japanese-level production efficiencies. We had to be profitable not only in a buoyant market, but also during the bad times which would inevitably come after it.

Traditionally, our production technology was developed almost independently by each factory, and often only by the respective production establishment. Efforts in this field were not centrally coordinated and this created a dispersion of effort and a reduced information exchange between factories. To overcome this, management decided in 1989 to concentrate Research and Development efforts in the improvement of the production system, cancelling many technology programs unrelated to this goal. A company senior Vice-President was assigned to lead this work with exclusive dedication and functional authority over all factories. A small new staff was created to coordinate the efforts.

From the initial analysis, the Japanese shipbuilding model appeared unattainable. Many of our own experts thought we could never reach their levels of efficiency due to complex social reasons and our different industrial background. In consequence, there were hot arguments about trying to follow the Japanese shipbuilding example, and many suggested that more modest goals should be set. There was also a tendency to think that shipyard productivity improvements could only come through working harder, or via investments in better facilities or hi-tech equipment, such as covered building halls, automated production lines, CAD/CAM, robotics or lasers, with rather lesser attention being paid to industrial engineering considerations.

In the end, the analysis showed such a substantial gap in productivity between Japan and the next best that our management decided in favour of the Japanese model, no matter how difficult. Any other option, it was thought, would lead to insufficient productivity improvements. Around mid 1989 it was decided to revitalize the Japanese cooperation programs. However, before

resuming the trips to and from Japan, a review was made of previous cooperation programs to find out where they were successful and where they could be improved. All work processes were analyzed, starting with the most advanced yard at Puerto Real, and a long list was prepared, including questions to be asked and aspects to be discussed with our Japanese consultants. It was evident from this analysis that a lot had been learned in previous years regarding detailed aspects, and little or nothing in the more general aspects of engineering organization, planning and production control. This was confirmed by a first trip back to Japan in the fall of 1990. A new approach was required. We needed to learn not only what the Japanese were doing, but also why they were doing it.

THE PATH TO PROGRESS

The productivity circumstances surrounding the comeback of our shipyards were in many ways similar to those which led to the establishment of the National Shipbuilding Research Program in the United States. A limited number of our senior executives had followed with interest the developments in the NSRP during the eighties, especially through the NSRP publications and the Journal of ship Production, a truly unique magazine. Some had tried to apply certain concepts discussed in the NSRP literature, but due to external circumstances they were unable to muster sufficient support and their efforts faltered. However, by late 1989 there were more and more people in our organization who believed that an integrated effort similar to the NSRP could be the key for bringing together and understanding the piecemeal knowledge acquired in the previous 15 years about Japanese shipbuilding methods. A decision was made to investigate the program, and its operational concepts.

Some of our R&D staff attended the 1989 Annual Meeting of the Society of Naval Architects and Marine Engineers in New York, followed by a brief SNAME-sponsored workshop on design for production integration led by Prof. Howard M. Bunch, chairman of the Journal of Ship Production Committee and the NAVSEA Professor of Ship Production, University of Michigan. We found strong connections between the areas where our group was planning future research and those covered by NSRP studies. In particular, problems affecting productivity in the

American shipbuilding industry (1) were often relevant to our own case. Our experts were impressed by the fact that most of the material presented at the workshop had been developed by the NSRP. When they returned to Spain, they recommended the launching of a group-wide R&D program to conceptualize the Japanese shipbuilding model, translate it to our own parameters and later develop a comprehensive scope of detail implementation projects. These goals were very similar to those which originated the NSRP more than ten years before.

Early in 1990 a team again visited the United States and held extended interviews with several individuals concerning modern shipbuilding production concepts and, among other things, the structure of the NSRP and its focus. It was also hoped that the trip would be useful in establishing future contacts with American shipyards for development of areas of mutual interest. To show the importance attached to the trip, AESA's Chairman/CEO led the team. Among those interviewed was Mr. Louis D. Chirillo, shipbuilding consultant and author of some of the most impressive papers and publications we had read, as well as leader of many relevant research projects sponsored by the NSRP. The team also visited Prof. Richard L. Starch, senior author of the textbook Ship Production and professor of Industrial Engineering, University of Washington, and again Prof. Bunch in Michigan. At the conclusion of the meetings, the three Americans were invited to visit the Spanish shipyards and to present their views on modern ship production. This established the basis for an ongoing relationship.

A few weeks later, Professor Bunch and Mr. Chirillo arrived in Spain and first made a week-long tour of the major shipyards, where they had opportunities to talk to many of the managers and to inspect production operations. At the conclusion of their visits, they made a presentation to top level management at the Madrid central headquarters. The presentations summarized the team's thoughts of where and how improvements could be made. They also addressed the dynamics of change; the ways that the knowledge might be most effectively incorporated into the production structure. The experts focused their recommendations, at least for the initial stages, towards the improvement of work organization, not facilities. The advice was "work smarter, not

harder," and the message was reinforced by numerous slides comparing how AESA did things and how it was done in the world's leading shipyards.

Shortly afterwards, AESA organized two one-week courses for senior and line-level managers in technical offices, production, planning and procurement departments of the two most important yards. Mr. Chirillo and Professor Starch were instructors in these seminars, which were attended by more than 50 people. The main stress of these seminars was the application of group technology in shipbuilding, with the application of zone/stage/type-of-work principles to ship construction.

Because our shipyards are state-owned, we informed the Spanish Administration of the results of our American contacts. As a result, Mr. Chirillo was retained in the position of adviser to the Spanish Private Shipyards Association, with full governmental backing. Due to their small average size and lack of individual resources, the Association's thirteen shipyard members were being temporarily helped by the Administration through a reconversion period. So, although we have been competitors in some specific cases, we are in fact contributing, and happily so, to the improvement of domestic private yards.

THE GLOBAL PLAN FOR TECHNOLOGICAL IMPROVEMENT 1990-92

In April 1990 the new production policy was made official by the group's top management, and a comprehensive R&D program called the Global Plan for Technological Improvement 1990-92 (PIMET for its Spanish initials) was launched (2). The main objective of the plan is:

"to organize, promote and coordinate the technological projects of the Factories and the Central Headquarters oriented to improve radically, in the short- and mid-term, the competitive position of the group's companies and to consolidate in the long-term the advances made."

The introduction further states: "In this respect, it is crucial to increase production as a way to increase income and to reduce labor costs as a way to reduce expenses. Both are achieved by technological improvements in the building

processes. These improvements are also essential to reduce delivery leadtimes, which in our case are considerably longer than those of our competitors. This additionally entails financial savings and helps to reduce inefficiencies. The reduction in leadtimes is achieved by the adoption of building systems based on the zone-per-stage concept, following the world's most advanced shipyards. These systems also favour the reduction of work content in interim products and finished products, which in turn lead to labor reductions as a consequence of the necessary reorganization of the manufacturing processes." Finally, the presentation clearly establishes the Japanese shipbuilding industry as our model of reference.

The Plan sets forth the following action policies:

1. Design for Production Integration:

1.1 To establish a stepped process for the definition of the vessel with coordinated advance of the design, planning and material management.

1.2 To reorganize the structure of the technical offices according to the zone-per-stage principle and to improve the quality of contract design.

1.3 To improve the relationship between technical offices and production departments, procurement departments and planning departments.

1.4 To develop CAD/CAM applications to support information flows and to produce the required graphic and written information.

2. Integrated Hull Construction, Outfitting and Painting:

2.1 Subdivision of the production processes according to Group Technology logics, in process lanes.

2.2 Reorganization of production teams in groups, each executing a work package defined by work instructions.

2.3 Distributing short-term planning responsibilities horizontally to the production sections.

2.4 Establishing interface relationships between production stages based on a "pull" philosophy.

2.5 Adapting facilities to optimize process lanes.

3. Planning and Control by Work Units:

3.1 Adapt planning units to process lane and interim product concepts.

3.2 Involve in planning all parties affected; technical, office, procurement and production managers.

3.3 Establish reliable production and productivity databases organized according to interim products.

3.4 Organize material coding schemes according to Group Technology principles.

4. Continuous Improvement of the Manufacturing System:

4.1 Establish a dimensional control system for all processes, based on statistical concepts.

4.2 Disseminate the basic production engineering techniques among those involved.

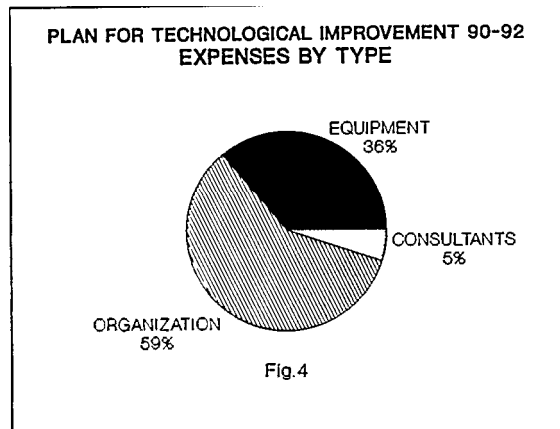
4.3 Set up a production engineering group in each Factory.

4.4 Formalize and document a building strategy for each newbuilding.

4.5 Define and develop production systems to be automated, and the CAD/CAM applications necessary for this purpose.

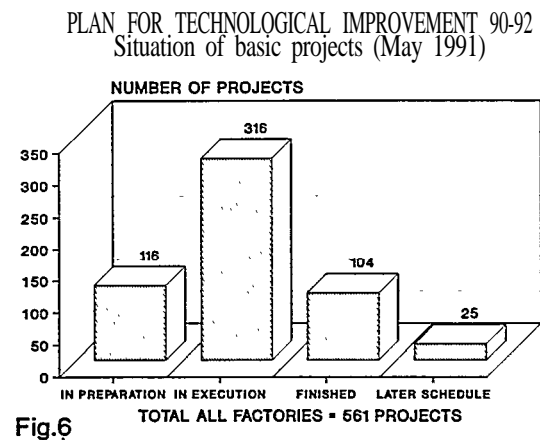
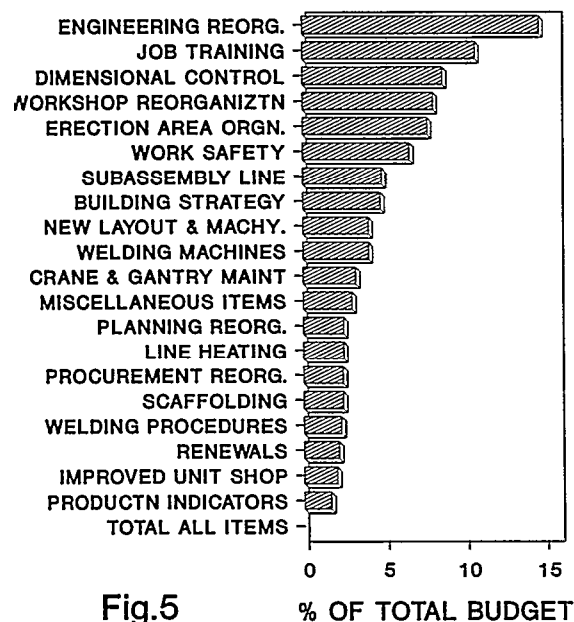
4.6 Set up management-by-target procedures and direction-by-objectives pay systems.

About US\$ 110 million have been allocated to the implementation of the Plan, of which about two thirds will be devoted to soft-technology aspects, or industrial engineering. See Fig.4. The remaining third will be directed at improving facilities, but only after organizational



improvements of the respective areas take place. The Plan incorporates 561 initiatives covering the full engineering, planning, procurement and production spectrum. A typical factory has between 60 and 120 projects, depending on size. Grouping the respective budget by type of initiative, a very strong emphasis in soft technologies can be seen. See Fig.5. Some 20% of the projects are already finished, while another 55% are now underway. The rest will be carried out in 1992. See Fig.6.

**PLAN FOR TECHNOLOGICAL IMPROVEMENT
PUERTO REAL FACTORY
PROJECT BUDGET BY TYPE**



**CONTINUATION OF THE AMERICAN AND
JAPANESE RELATIONSHIPS**

In October 1990, Mr. Chirillo returned to visit our remaining six shipyards, three of which were devoted exclusively to repairs. The following month, Professor Bunch came to Spain again, this time for a presentation to top management on the implementation of change in an industrial environment. This was followed by a one-week design for advanced ship production seminar especially addressed to technical office personnel and attended by 30 persons. By year-end practically all top executives and people in responsible positions within the engineering, planning, procurement and production processes had been exposed to the new ideas. Additionally, the company had implemented a program of acquisition, translation and circulation of selected technical publications, including the Journal of Ship Production and a number of the NSRP manuals which described the Japanese shipbuilding model.

At this time, a much better understanding of Japanese shipbuilding processes exists in our company. This result might have been reached directly by our experts thanks to the abundance of Japanese-supplied material from past and present co-operation periods. However, it was facilitated by the NSRP's identification of the logic and principles of Japanese shipbuilding methods and its clear exposition in an easily readable language.

This has permitted the successful organization of brand-new cooperation agreements with leading Japanese shipbuilders for the implementation of productivity improvement concepts and total quality control (TQC)

processes in our group's two most advanced shipyards over a 3-year period. These projects will supplement, and run in parallel with those of the PIMET Plan. The goal is now to put the group on a par with world-class shipbuilders regarding production efficiency. This requires at least duplicating the present productivity levels.

The Japanese experts now visiting our yards are finding a more receptive environment for their ideas, with far more cooperative managers and workers. This is making their task easier and progress is being achieved faster than expected, and certainly much faster than in any previous period of cooperation with Japanese companies. Many of the participants are the same, but we have a new mentality on our side. The rethinking process which has taken place in the last two years is the key to the change in attitudes.

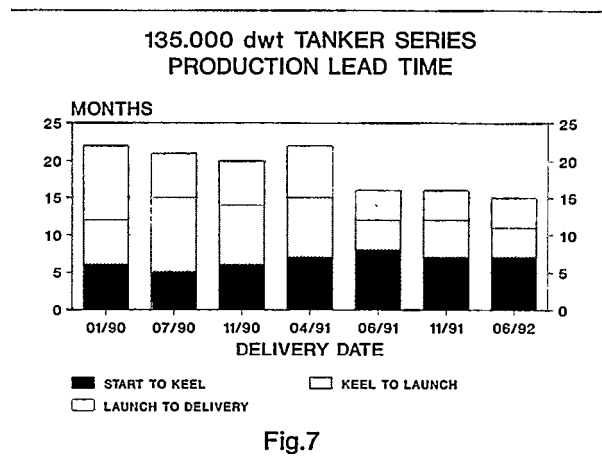
RESULTS

Only about a year after the publication of the PIMET Plan and the visits by the American consultants, each of our newbuilding yards had already developed a Product Work Breakdown Structure (PWBS) based on Group Technology (GT) and Interim Products according to its own unique facilities. For new contracts the yards are now preparing detailed building strategies according to Integrated Hull Construction, Outfitting and Painting (IHOP) principles. Work is classified by GT and process lanes have been formalized. A task group is now introducing line heating techniques for accurately shaping plates and profiles. Engineering departments are now organized according to the zone-per-stage-work-intrusion concept and, last but not least, basic designs have been extended in their scopes and are now developed with full attention to production aspects. Each factory has chosen a slightly different path in order to cause minimum disruption to on-going ship construction. But by the end of the PIMET plan, all factories are expected to have reached full development of the new production philosophy.

It is a little too soon to talk of productivity results. Steel is now being cut for the first vessels which will benefit from the new technologies. Their construction will be followed with keen interest to determine the effectiveness of the measures taken in what is already considered within AESA as a new technological era. In one case of series production, leadtime has been

reduced considerably, while improving the accuracy of planning. See Fig.7. This is due mainly to improved pre-outfitting and increased modularization of piping and machinery systems. Our global productivity, measured in Compensated Gross Tons (CGT) per man-year has also improved dramatically in the last three years. See Fig.3. Again, this is as much due to full capacity utilization as it is due to better procedures and organization. However, the real improvements are yet to come when the full scope of changes are applied.

Meantime, in anticipation of PIMET-induced productivity improvements, some yard production managers have already accepted manhour targets for new designs which are about 20% lower than the previous levels.



ACKNOWLEDGEMENTS

We want to express our gratitude to Mr. Chirillo, and Professors Bunch and Storch, for the enthusiasm they have put in our projects and the invaluable advice they have given us throughout. Thanks to Mr. Watanabe, of Mitsubishi Heavy Industries, and the managers of their Kobe shipyards for the untiring interest they have put in our collaboration agreement. Thanks also to Mr. Alan Nieremberg, formerly of Avondale Shipyards, for a very enlightening explanation of their shipbuilding philosophy. Finally, thanks to the NSRP for a most refreshing and motivating effort.

In retrospect, a very important guide for evaluating the situation of AESA and indicating a direction of movement for AESA's structure was the work related to the NSRP. It provided a useful means for the organized interpretation of Japanese shipbuilding concepts, even to those who were already familiar with these concepts. In the NSRP, AESA also had visible evidence of how a determined effort involving industry, government and academia can effectively set directions for shipbuilding industry attempts to move forward towards significant improvement of its production structure.

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Breaking the Chains of Tradition and Fantasy - A Revolutionary Approach to the Constraints on Productivity

IIA-2

James Rogness, Member, Peterson Builders, Inc.

ABSTRACT

Productivity improvement is becoming an ever more crucial agenda item for the U.S. Shipbuilding Industry. Initiatives to improve productivity in U.S. shipyards have traditionally taken the form of piecemeal efforts to increase capability and capacity through technological upgrades of production methods, facilities, tooling, and machinery. In spite of the fact that those initiatives have been successful in eliminating many of the physical constraints of productivity, a broadening productivity gap with foreign competitors places U.S. shipbuilding in a noncompetitive position in the international commercial market.

The continuing failure of technological initiatives to narrow the productivity gap does more than suggest that additional measures need to be taken. It strongly indicates the presence of productivity constraints which exist beyond the realm of technology. In fact, one of the most valuable opportunities currently available to U.S. shipbuilders may exist in the realization that many of the constraints limiting productivity in shipbuilding are actually self-imposed, arising from traditional management and organizational policies which run counter to the new and changing realities of modern industry.

INTRODUCTION

At the 1990 Ship Production Symposium in Milwaukee, Professor Ernst G. Frankel, Massachusetts Institute of Technology, presented a paper entitled, "The Path to U.S. Shipbuilding Excellence -- Remaking the U.S. into a World Class Competitive Shipbuilding Nation." Based on a critical assessment of the status of U.S. shipbuilding in perspective of the international commercial market, the salient message was a call for "radical change in the way U.S. shipbuilding is organized, managed, operated, and does business." To reinforce the rationale and urgency

of that message, it would be useful to review selected portions of Professor Frankel's presentation:

"Lack of access to or availability of technology is therefore not the reason for the continued lack of improvements in U.S. shipbuilding competitiveness and productivity. Labor productivity in terms of manhours per unit of output is only 40% of that achieved in Japan, and 82% of that of Korean yards. U.S. shipyard overhead costs, which include administration, inventory, underutilization, and other costs, are significantly higher than those of comparable yards abroad even though most U.S. yards have access to advanced manufacturing management technology..."

"It requires learning from the past and designing for the future, and focusing on shipbuilding as an integral manufacturing system. Piecewise technology adoption to solve narrow or parochial problems so prevalent in the recent past have often caused new and sometimes more serious problems. This approach must be replaced by new collaborative methods in which product and process technology is developed and effectively used by cooperation among clients, shipbuilders, workers, suppliers, and government or regulators. This will require breaking down of barriers of mistrust which invariably led to adversarial relationships between clients and shipbuilders; shipbuilders and suppliers; shipbuilders and regulators; and, shipbuilding management and workers."

"Most essential is the improvement of U.S. productivity...Productivity in U.S. yards is affected by several historic, institutional, and structural factors...The different causes

and their contribution to low yard productivity and competitiveness (or high cost of production) are:

1. casual labor practices and high labor turnover;
2. ineffective marketing, customer communications, long shipbuilding lead time, and customer control over design and certain procurements;
3. ineffective, nonresponsive, hierarchical organization and management structure;
4. comparatively low level of education and training of workers, staff, and management;
5. lack of effective operational integration and intra labor as well as labor-management communications and cooperation;
6. inadequate yardwide strategic planning of technological change or piecewise technology introduction
7. ineffective procurement and inventory management
8. lack of total quality management
9. restrictive union practices, such as work rules, seniority systems, and opposition to technological change, or changes in work procedures;
10. lack of effective design/production integration or design for producibility;
11. short horizon management;
12. lack of discipline, loyalty, and commitment by staff and workers."

THE PRIMAL SCENARIO

Professor Frankel's words prompt questions such as, How does work really get done in U.S. shipyards? Do ships get built as a result of a shipyard's formal systems, or in spite of them? The standard company answer would probably be that the engineering function designs the ship; the planning function defines and schedules the entire construction process; the procurement function prices and purchases the material; the warehousing function receives and stores the material; the production functions build the ship; the human resources function acquires and maintains the workforce; the quality assurance function assures quality workmanship and compliance to contract specifications; the contracts administration function interfaces with the customer; the marketing function bids new contracts; the data processing function supplies all functions with needed information; the facilities

function maintains buildings, machinery, and equipment; and the accounting function monitors the performance of all other functions.

At the peak of the organization, the executive command and control center directs a hierarchy of management and supervisory personnel engaged in deploying workers and holding them accountable for cost and schedule performance. It should be noted that several variations of organizational structure have evolved in other industries, but U.S. shipyards have essentially remained oriented toward a military hierarchy of centralized functions with vertical chains of command.

On the surface, everything appears to be neat and orderly. With all functions effectively pigeonholed and even some standard operating procedures in place, employees should have a clear idea of what they have to do and when, where, and how they must do it. Below the surface, however, a differing view of reality displays a disjointed manufacturing process lurching out of control as emergent fires burst into flame. Witness the Primal Scenario...

The engineering staff is rushing to pump out drawings that have fallen behind schedule. Why? The reasons are now being brainstormed by engineering department managers and supervisors in a hastily called meeting to prepare for an anticipated executive inquisition. The brainstorming concludes with the following results:

1. Insufficient manpower because of the executive hiring freeze on all support departments;
2. A continuous stream of customer change requests;
3. Late VFI (vendor-furnished-information) due to the material procurement department being behind schedule;
4. A design subcontractor who developed drawings in the wrong sequence;
5. CAD (computer aided design) operators that are not yet fully trained; and,
6. Some troublesome technical specifications that somehow went unnoticed in the bidding process.

The good news is that a prior executive directive to dissolve the drawing review team to make more draftsmen available has enabled engineering to make rapid schedule recovery.

The same type of emergency session is occurring within the departmental walls of material procurement. The following strategy is being developed to appease executive management. Purchasing appears to be behind schedule because engineering has been late in developing technical

specifications and because vendors are generally becoming less and less responsive to the shipyard. The good news is that schedule performance is not as bad as it appears, because the schedule is wrong. Many material items are simply not needed as early as dated in the schedule. Even better news is that during the past year, several new vendors have been found with lower prices, therefore the shipyard is now realizing substantial savings in material cost. Permission is requested to hire three more expeditors to put additional pressure on vendors.

Strong executive displeasure with unfavorable cost and schedule performance in the production trades has been flowing down the chain of command for quite some time. Stricter measures have been taken to hold the trades more accountable for their performance. Accounting has issued a doomsday report to executive management. A top secret executive session will be held tomorrow and, this time, heads will roll. That news has placed production department heads and supervisors in varying states of frenzy and fear. How can we stay on schedule if drawings and material are late? Or worse, what if we have to rework half of what we accomplish because of drawing errors? Or worse yet, do they know that the cheap new material they've been buying lately more than triples our hours on some jobs? What good are meaningless schedule dates and work order estimates? Don't they realize what this mess does to morale? It's hard enough to get people to work when things are going right. Who's in charge of this place, anyway? Don't they see what's going on?

Production workers sense their bosses' frustration, but react with indifference. Long conditioned by the fact that their thoughts and ideas do not count for much in the shipyard, work has become an activity of "doing time" in order to earn money to finance the rest of their life. Their priorities are dominated strongly by activities and pursuits outside of the shipyard -- a place where the thoughts and ideas of working men and women still count for something. They feel little sense of loyalty to the shipyard, because the shipyard belongs to other people -- the people who own the business and the people who run the business.

The prevailing attitude of the workforce becomes one of: "Who cares? Why should anyone care? The more you do, the more they expect. If they fire me, they fire me...I was looking for a job when I found this one...It all pays the same..."

In viewing the stark and unpleasant Primal Scenario, the most telling setting is a shipyard celebration of the completion of a contract. The congratulatory and appreciative executive rhetoric

is sincere, but rings hollow as it falls upon the cynical ears of an alienated workforce. In the final analysis, who can blame them? They are only responding to the manner in which they are treated.

ESTABLISHING A FOCUS

In viewing the Primal Scenario in perspective of Professor Frankel's twelve causes of low productivity, a clear picture of the paralyzing dilemma which is plaguing U.S. shipyards begins to emerge. There seem to be so many problems of such magnitude that one hardly knows where to begin. The fact that other industries face the same dilemma is small consolation. The fact that a vast array of glistening new manufacturing strategies and integrative software systems is being offered by waves of highly-polished consultants only adds to the confusion.

Perhaps a good place to begin is to look a little more closely at the list of twelve causes. Are they actually causes? It seems fairly obvious that each item contributes to low productivity, but why do the twelve items, themselves, exist? What is causing them? The situation is much like a person who is not feeling well. Is that person ill because of the symptoms being experienced, or because of the ailment causing the symptoms?

If we redefine the twelve causes as being major contributing factors to low productivity, but symptomatic of a greater ill, what do the twelve symptoms have in common? Two commonalities appear to be interwoven among the twelve contributing factors:

1. All stem from ineffective management; and,
2. All adversely affect the entire workforce.

Consider Dr. W. Edwards Deming's assertion that, "The biggest problems that any company in the Western World faces are not its competitors... The biggest problems are self-inflicted, created right here at home by managements that are off course in the competitive world of today. Systems of management are in place in the Western World that for survival must be blasted out."

It would be reasonable to conclude that many, if not most, factors contributing to low productivity in shipbuilding are directly attributable to deficiencies in shipyard management, but is that such an astounding revelation? (Shipyard workers have known this for years.) To break new ground, we must delve deeper to focus upon the specific characteristics of ineffective management, characteristics which are revealed in the nature and origin of shipyard organizational policies which are blocking the path to shipbuilding excellence.

PROBING HALLOWED GROUND

U.S. shipyard executives do not have enough time to spend on the issue of low productivity. The politico-economic ramifications of market demand, capital availability, a shrinking supplier base, rapidly advancing technology, foreign subsidies, labor relations, and environmental regulations represent formidable challenges in strategic planning; but there is not enough time for strategic planning, either. Too much of a shipyard executive's schedule is required to direct the battle against the emergent fires of the Primal Scenario.

Even if more time were available, however, it would probably not be spent in devising ways and means of improving productivity. That responsibility has usually been delegated to middle management and line supervision, because of a traditional misconception that productivity improvement hinges primarily upon the elimination of *physical* constraints in the shipyard. Middle managers and supervisors often perform well in addressing the physical constraints of productivity *within their own departments*, but are powerless when confronted with constraints imbedded in organizational structure and policy -- the exclusive domain of executive management. Managers and supervisors do not often question organizational policy, because that simply is not the way to survive, much less advance, in an authoritarian hierarchy of command and control.

Managers and supervisors act in accordance with the criteria by which their performance is measured: the ability to take orders; the ability to effectively command their troops in the accomplishment of assigned objectives; and loyalty to their superior. Even if they were so inclined, they are far too busy on the front lines of the firefight to have the time for philosophical pursuits. Every effort is made to contain and conceal the emergent fires. Whatever the cost, unfavorable attention must not be drawn to their own area of responsibility or to their superior in the hierarchy of command.

The irony is that even though U.S. shipyard executives have not recognized the opportunities inherent in questioning and changing basic organizational policies, they have not hesitated to experiment randomly with change, itself. Quite a number of concepts and methods have been explored, including: quality circles, profit-sharing, pay for performance, management apprenticeships, quality of worklife, integrated business systems, participative management, performance measurement, functional work teams, cross-functional work teams, job enrichment, suggestion systems, increased training, and improved communications.

Also explored have been the "quality" approaches of SPC (Statistical Process Control) and TQM (Total Quality Management); the "top down -- bottom up" strategic planning approaches of MB0 (Management By Objective) and MOR (Management by Objective for Results); and structural analysis and design techniques such as IDEF (Integrated Computer Aided Manufacturing Definition).

The problem is that, despite all that has been considered and tried, results have been disappointing, at best. No shipyard has been able to break out of the pack and lead the way to international competitive stature. What more is needed? What more can be tried? The answer to those questions is not comforting. No procedure, tool, or program, *in and of itself*, is capable of boosting U.S. shipbuilding productivity into international competitive stature. Very little improvement is possible until shipyard executives finally realize that the most powerful productivity constraints in U.S. shipbuilding exist in the form of destructive organizational policies *which on/y they can change*.

THE CONCEPT OF RADICAL CHANGE

The key words of Professor Frankel's message of a year ago are "radical change." The concept of radical change is easily misunderstood. Radical change does not necessarily require drastic or extreme action, but it always requires the freedom to question. Radical is defined by Webster as being "of or from the roots; going to the center, foundation, or source of something; fundamental and basic."

Consider the fact that battling the daily emergent fires of the Primal Scenario has become a traditional, self-perpetuating source of futility and frustration. It is war without end, because the fires are only symptoms of deeper problems which go unresolved. The good news is that there is a way to end that war. It begins with realizing that *the discovery of just one false assumption at the core of a business problem eliminates the symptoms by resolving the problem*.

Just how much radical change is occurring in the way U.S. shipyards are structured, organized, and managed? Perhaps more importantly, how many shipyard executives feel compelled to run the risk of challenging tradition in order to bring about radical change? Is it realized that nothing short of radical change is required? Is it realized that U.S. shipyards are being held in bondage by powerful, destructive forces of tradition and fantasy? Is it realized that those forces obtain their power only from our reluctance to question?

Tradition is defined by Webster as “an inherited, established, or customary pattern of thought, action, or behavior.” Fantasy is defined in the sense of illusion, “the state of being intellectually deceived or misled.” There is no inherent risk in following tradition, but there is substantial risk in the blind acceptance of tradition; especially if that tradition is based on the deceptive illusions arising from false assumptions.

It is very difficult to overcome the inertia and incumbency of tradition in an environment where it is not realized that all facets of a tradition are nothing but precipitates of earlier changes. It is extremely difficult for a creative thinker to survive in a repressive environment which *enforces* unquestioning acceptance of tradition, rather than *allowing* the vigorous pursuit of new knowledge. Perhaps, it should be realized by those who resist radical change in shipbuilding that the risk of following a tradition based on the illusions of false assumptions is far greater than the risk of creating radical change.

THE CHAINS OF TRADITION AND FANTASY

Hierarchical organizational structure has existed for thousands of years in types of organizations as diverse as government, religion, and industry. It is a logical structure of authority which traditionally has been used by the “few” at high levels of the pyramid to control the actions of the “many” at lower levels of the pyramid. The dawn of an industrial era demanding major advances in flexibility and adaptability, however, has caused the hierarchical structure to come under considerable scrutiny and criticism. Inherent tendencies toward the centralization of authority and the distortion of information as it is communicated either up or down through the levels, have been recognized to be critical flaws resulting in functional rigidity, unresponsiveness, and inefficiency.

The Impotency Of Centralized Authority

Valuable lessons for industry are borne out in the successes and failures of contrasting types and styles of governments. Perhaps the most important lesson is the essential weakness of centralized authority. What do democracies, monarchies, and dictatorships, whether fascist, socialist or communist, all have in common? All are governmental hierarchies based on politico-economic doctrines which seek to control people and material wealth. They differ in many respects, but the most important distinction is in the assumption each makes as to the ability of people to make wise and just decisions. Democracies take the view that people are generally able to make wise and just decisions, and thus place

significant power in the hands of the governed. Monarchies and dictatorships take the opposing view and centralize power within a ruling elite.

The essential weakness of centralized authority is seen in the following downward spirals of logic, which apply to all types of government, including American democracy. The fundamental pattern that will be revealed is: as authority becomes more centralized, emerging factors of rigidity, unresponsiveness and inefficiency cause the need for even greater control.

The more decisions that a government makes for its people, the greater the need for a bureaucracy to communicate and enforce those decisions. The greater the bureaucracy, the less responsive a government becomes to the needs of its people. The less responsive a government becomes to the needs of its people, the more dissatisfied the people become. The more dissatisfied the people become, the greater the need for governmental control.

The more decisions that a government makes for its people, the fewer decisions that people can make for themselves. The fewer decisions that people make for themselves, the more dependent they become upon the government. The more dependent the people become, the less able and productive they become. The less able and productive the people become, the more dissatisfied they become. The more dissatisfied the people become, the greater the need for governmental control.

History has repeatedly shown that the pursuit of centralized power and authority is directly opposed to efficiency and effectiveness in government hierarchies. Can there be any basis for believing that the same logic does not apply to industrial hierarchies? Consider the lack of control so evident in our shipbuilding process. Consider the morale of workers in our shipyards. Consider how frequently the observation is made that the quality and capability of the workforce has severely declined.

Those conditions stem from the false assumption that all decisions regarding shipyard operations should be made by the ruling elite, consisting of shipyard executives, managers, and supervisors. What is not realized is that such an approach to attaining more control actually results in more inefficiency and less control. Also what is not realized, especially by executives, is that the shipyard they are trying to manage, often does not even resemble the shipyard which actually exists.

The Origins Of Distortion

Wise decisions require accurate information. It stands to reason that the more levels of bureaucracy in an organizational structure, the

more chance there is for information to be distorted as each level reinterprets the information that it receives. That creates a problem for shipyard executive management located at the end of the receiving line, but an even greater problem is caused by the fact that a typical U.S. shipyard has applied the concept of centralization to each of its major functions. The grim result is the existence of mini-empires with distinct *territories* to defend, thus ample incentive to distort management information.

The vertical chains of command within centralized shipyard functions create a situation which demands a type of misdirected loyalty that can be devastating to the company, as a whole. It is a policy which rewards allegiance to one's function and one's superior in the chain of command and severely punishes any breach of that allegiance. In situations where what is best for the department is not in the best interest of the company, such a policy acts to suppress accurate information while encouraging inaccurate information. The valuable employee attributes of honesty and genuine concern for the company become twisted into the undesirable traits of a trouble-making maverick who is not a "team player" in the department.

By far the most prevalent cause of distorted information, however, is the tendency of executive management to react to unfavorable cost and schedule performance by exerting additional pressure on the command and control structure. That is done by enforcing stricter discipline in an attempt to hold managers and supervisors "accountable" for the performance of their departments. Somehow, it is assumed that it is possible, and even desirable, to hold employees accountable. Two problems exist with that assumption.

First, it is unfair to hold managers and supervisors accountable for performance which is frequently impaired by disruptive factors originating elsewhere in the shipyard and, therefore, beyond their control. That unfairness, coupled with the factor of inherent loyalty to department or function, elicits the predictable response of blame being directed toward other functions. Before long, blame is being directed everywhere, mounting tensions choke off communication and cooperation, the walls between departments stiffen, and departments become polarized.

Second, accountability is much like the subject of lower taxes -- it is always talked about, but it never seems to materialize. It is simply not possible to hold an employee accountable for anything. The person can be threatened, punished, or even dismissed, but such actions will

not produce accountability. Genuine accountability is self-generated. It arises from within an individual as a sense of responsibility toward the values held by that individual. Employees who take pride in the quality of their work and realize that it is in their best interest to care about the future of their employer *will hold themselves accountable*.

The Illusion of Control

Suppose that we postulate that it is in the best interest of a shipyard, as any business, to make more money now, as well as in the future. To best serve that end, what is the proper role of shipyard management? There is an interesting phrase in Webster's definition of the term "management" which reads, "judicious use of means to accomplish an end." The question is, what means should be used? The inadvisability of centralized command and control of shipyard operations is quite apparent. How then should management control shipyard operations and personnel?

The problem in answering that question stems from the fact that it is based on the false assumption that shipyard operations and personnel can and should be controlled by management. That false assumption has resulted in devastating management practices such as the traditional method employed by shipyard cost accounting to control financial performance. The highest priority in traditional cost accounting is to improve the bottom line through cost control. Though it seems prudent to try to control costs, all hints of wisdom vanish when cost control becomes shipyard management's highest priority.

The folly of such practice is illustrated by the fact that the potential for increased profit through cost reduction is limited to the amount of waste in current operating expense, but the potential for increased profit through expanded output, marketing, and sales of higher quality products is limited only by imagination. It is disturbing to realize that prudent, but misplaced, management priorities have often blocked the path to shipbuilding excellence by denying investment in vital research and development, process engineering, and marketing. It is truly regrettable that the same misplaced priorities have played a prominent role in devaluing a shipyard's most valuable resource -- its people.

As a line item on a ledger, labor is a cost of doing business. As a factor in the equation of greater productivity and profitability in shipbuilding, labor is the most important investment a shipyard can make. Traditional actions taken by U.S. shipyard management to control costs invariably focus on cutting the roll of

departments displaying excess labor capacity. Such actions disregard the fact that excess labor capacity may be a result of operations that are more productive than departments with insufficient labor capacity.

Why should workers strive to be productive if it means early unemployment? What sense of loyalty can a worker have for a company that appears to be more concerned about cutting costs than it is about the job security of its workers? Despite any rhetoric to the contrary, the actions of shipyard management repeatedly signal the message that a shipyard worker is regarded to be a highly expendable item -- not a highly valued investment.

The false assumption that shipyard operations can and should be controlled by management is a classic example of confusing ends with means. It is reasonable to want a shipbuilding process that is "under control," but it has been proven time after time that such a capability cannot result from stricter control measures. What will it take to elevate the role of shipyard management from the defensive posture of reactionary authoritarianism to the positive stance of creative leadership? What will it take to elevate the role of shipyard workers from that of expendable pawns to the status of world champions in shipbuilding excellence? Perhaps it is time to explore the rationale and means for freeing up operations and workers, rather than attempting to control them.

BREAKING FREE

There are many management theories available for shipyard executives in search of the elusive recipe for creative leadership in manufacturing excellence. Some theorists approach the issue from the perspective of management tools and systems development, some from the perspective of management configuration, and some from the perspective of organizational culture. Thus far, however, there appear to be no shortcuts and no reliable step-by-step instructions to guide U.S. shipyards to the attainment of international competitive stature.

Perhaps it would be wise to consider the thought that leadership in business really has little to do with *following* instructions, anyway. The price of leadership is the intellectual effort required in *creating* new and better ways of doing things. That intellectual effort accepts nothing at face value, but acts to strip away the sacred veils from traditional management values, structure, and policy. Current practices are questioned relentlessly until the false assumptions at the roots of complex business problems are finally exposed.

Such an intense, intellectual offensive appears to be the best, if not the only way for U.S. shipyards to break free from the stranglehold of authoritarian bureaucracy. Such an effort has the power to spawn rapid, revolutionary change because thought and action are focused on fundamentals rather than on acronyms and abstractions. The speed of advancement can only be constrained by whatever persistence is shown to defend the status quo against inquiry and change. That constraint is directly proportionate to the degree of ability, desire, and commitment of shipyard executives.

Revolution is not to be taken lightly, for it can destroy as well as create. The central theme for the intellectual revolution needed in U.S. shipbuilding must be the creation of a new working environment -- a dynamic workplace where all workers are treated as professionals requiring freedom from bureaucratic controls in order to perform their jobs effectively. There is no attempt to control or discipline workers. Management is focused solely on facilitating the flow of resources and operations. Shipyard operations are not viewed in terms of departmental functions, but in terms of interrelated manufacturing processes. Process engineering is not pursued solely in terms of systems development, but includes equal emphasis on the facilitation of human interaction.

The new environment must provide and maintain inviolate freedom for all workers to question and dissent without reprisal. As controls are relinquished, authority must be decentralized in accordance with the belief that influence and responsibility in decision-making should be based on technical competence and knowledge rather than on personal or political prerogative. The new environment must not be characterized by *formalized* programs of training, strategic planning, performance measurement, or company-wide systems integration. It must be characterized by the availability of resources and assistance to all workers in *their* quest to improve performance.

How would workers respond to such changes? There is strong reason to believe that such fundamental philosophical changes could combine to unleash astonishing productive power currently suppressed by the bureaucratic culture which has become the overriding tradition in American government and industry. Consider the words of Lawrence A. Bossidy, vice chairman of the board and executive officer of General Electric Company:

"The American worker is not docile. He refuses to sing company songs. He makes fun of pompous fools in high places -- but he possesses a curiosity, a free-form creativity, and an intensity of response when challenged

that in my view is absent in the regimented cultures and hierarchical corporate structures of most of our offshore competitors. After a decade of reading a seemingly interminable series of books on how to become Japanese, it is gradually dawning on us that what we must do in the '90s is become more American."

The future success of U.S. shipyards may be in direct proportion to the degree in which the individualism, creativity, and competitiveness of the American shipyard worker is liberated and encouraged to flourish. The problem is that shipyard workers have generally become cynical, distrustful, and alienated toward management. In both subtle and overt ways, workers have been robbed of their self-esteem, which has sapped their desire to excel and take pride in their accomplishments. In the worker's mind, management has become the adversary. It will take nothing short of a revolution in management values, structure, and policy to break free from the past and build a new environment based on mutual trust, respect, and loyalty.

EPILOGUE

The intent of this paper is not to cast blame upon shipyard executives for the productivity constraints in U.S. shipbuilding, but rather to raise questions, stir debate, and perhaps break some new ground in management philosophy. The enemy of U.S. shipbuilding has been identified as authoritarian bureaucracy. The action that has been proposed is an intellectual revolution based on a simple rule: When data is accurate and reasoning is sound, but the answer is still incorrect; there is only one avenue remaining. Check the premises, the assumptions upon which the equation or argument is based.

Can U.S. shipbuilding break free from the chains of powerful productivity constraints? Can the courage be found to relinquish traditional controls? Can the strength be found to question all that we have been conditioned to accept without question? Can the wisdom be found to realize that the power and human morality of democracy applies to business, as well as government? Can the compassion be found to vigorously market all shipyard products and services in order to keep workers employed? Can the vision be found to invest heavily in research and development of the finest integrated manufacturing processes in the world? The answer to all is, "Yes it can, and I hope it will."



Panel Line Developments

IIB-1

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PANEL LINE DEVELOPMENTS

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ABSTRACT

This paper presents the joint efforts of a research and development project between an American shipyard and an independent engineering company that would resolve issues impacting panel production. The project objectives follow:

Develop an efficient means to fit full penetration joints from one side with plates of unequal thickness having the stiffener side up.

Develop an efficient one-side welding method for full penetration joints with plates of unequal thickness having the stiffener side up.

Develop a flow of material for locating and fitting longitudinal stiffening that would be balanced with the rest of the line.

Develop a multi-torch, multi-process longitudinal stiffener welding machine that one person can operate effectively.

Develop a method in which transverse stiffening could be fit and welded efficiently with minimal manpower using semi-automatic equipment.

The development of these areas would decrease facility costs and increase productivity by:

Allowing totally conveyored panel production;

Reducing edge preparations;

Reducing consumable requirements;

Automating high continuous linear footage areas of flat panels;

Reducing dimensional distortion;

Reducing operator complications; and

Lowering overall system cost.

All data are supported by production information, research and travel to domestic and foreign shipyards. Preliminary and ongoing laboratory efforts are in progress to confirm that this type of Submerged Arc Welding (SAW) will consistently meet the requirements of current standards for military and commercial ships.

INTRODUCTION

Having command of the most cost effective shipbuilding methods involves the maximum use of mechanization in production of the basic structural elements in an assembly line manner, i.e., process lanes. The process lane is defined as a series of fixed work stations with permanent production services for construction of ship components having similarities such as shape, size, and weight. However, the increased mechanization of limited purpose or interim components of the ship's structure is not a new approach to shipbuilding and in its simplest rationale can be termed efficient management of shipbuilding. Ryoji Nishijima is credited with having initiated the movement to efficient shipbuilding in Japan. The impact was such that in 1965-66 the total tonnage built in Japan near equaled that of the rest of the world and fabrication costs dropped over 70%. Nishijima's work began after reading a book by an American who is credited with having an equal impact on the automobile industry-Henry Ford.

Flexibility Increases Cost Effective Production

In today's non-series shipbuilding market, steel process lanes are still essential for efficient shipbuilding but must be established to maximize flexibility in mechanized production to minimize the impact of non-standardized contracts.

For example, SAW, patented in 1930 and imported to Japan after World War II, was primarily used for two side panel welding. It is now used in virtually all positions and its use has been expanded far beyond panel welding. Other processes typically used in steel process lanes as early as SAW was, remain inherently the same but their use is now much more

imaginative. As these processes are expanded in use and flexibility, so should the areas of their function.

Conventional mechanized SAW one side welding of flat panels has mostly been applied to panels having the same thickness or stiffener side up for panels of unequal thickness. For this reason panel production must still bear the burden of facility and equipment expense for turning some of the panels to make second side welds.

Additionally, panel production has typically bottlenecked at the stiffener attachment stations so that the maximum efficiency cannot be realized from the panel welding area. Longitudinal stiffening cannot be handled in the same manner as transverse stiffening and though different sequences exist for their attachment, both require extensive time and labor in welding. Methods for alleviating this problem range from multi-million dollar robotics to labor intensive work stations. Though automation and process lane construction methodology have decreased hours here, the most efficient mechanization must include:

Ease of setup;

Versatility; and

Minimal operator complication;

and not at only one end or the other of a process lane.

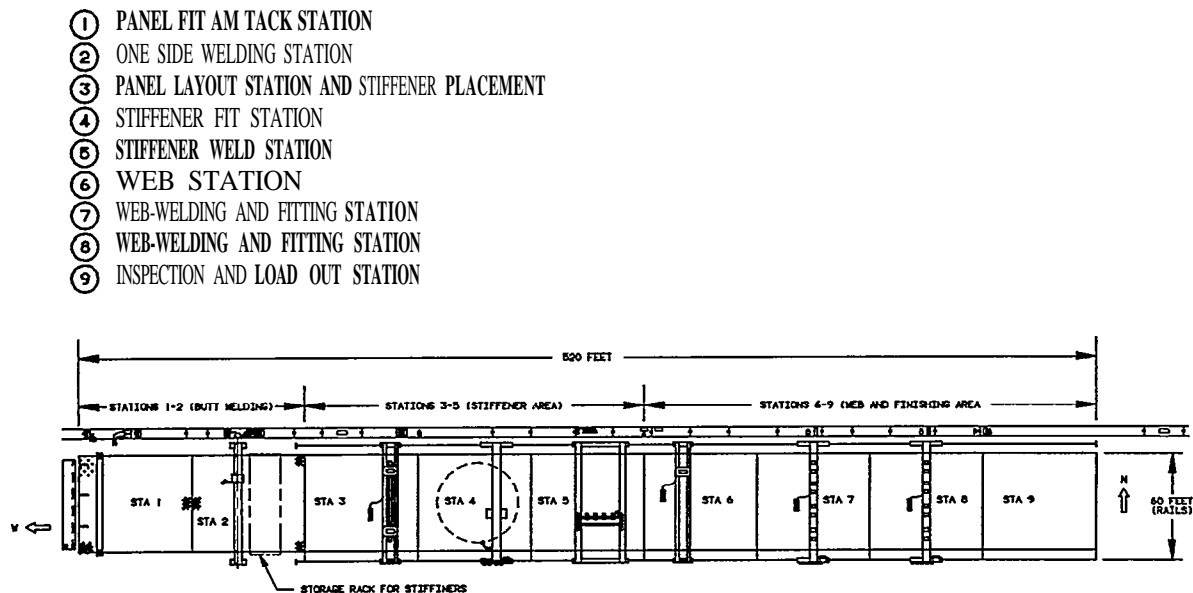
To ensure maximum efficiency from automation, a balanced workload is needed for a smooth material flow. A balanced workload can be effectively accomplished by separating the tasks into the sequences in which they are to occur in the direction of construction. It is here that automation is used to keep certain areas from becoming too labor-intensive. Hence the objective to reduce manhours can only be accomplished by the reduction of the workforce in a given area for a given budget.

In so doing, the production process will be enhanced and, depending on the work content per station, a completed structural component will leave the process lane at intervals equal to the allotted time for the assigned tasks regardless of total hours.

PRELIMINARY WORK BEFORE INSTALLATION

Requirements and Material Specification

Ship types were studied for comparison to ensure the broadest production range that could be handled cost effectively in the allotted time per station. Light combatants as well as commercial product carriers were to be processed by the same equipment specified as a result of the study. Additionally, a study of a structural system utilizing only longitudinal members for stiffeners as opposed to the conventional approach which employs



NASSCO PANEL LINE

Fig. 1 Stationized panel production

both transverse and longitudinal stiffeners was considered. Though equipment costs and lack of immediate need prevented the requirements from being in the specifications, provisions were made for upgrades should the need arise. Table I gives the range of material types and sizes that the equipment would be required to process.

Table I
Requirements and Material Specifications

Flat Plate

Plate thickness range:	6mm-38mm (1/4" - 1-1/2")
Maximum individual plate length:	15.85 meters (52' -0")
Typical individual plate width:	3.04 meters (10' -0")
Individual plate weight density range:	.42 -2153 kg/sq mt (10-60 Lbs/Sq.Ft.)
Plate joining process:	Oscillating DC/AC SAW
Joint design:	Beveled to suit thickness
Maximum completed plate length:	15.85 meters (52' -0")
Max. completed flat plate weight:	53,712 kg (144,000 Lbs.)

Stiffeners

Stiffener length maximum:	15.85 meters (52' -0")
Flange width range:	2.54-35.56 cm (1-14")
Web (height):	10.16-76.20 cm (4" -30")
Stiffener weight:	3.67kg/lin. met (300 Lbs/Linear Ft.)

Spacing between stiffener centerlines:	50.80-76.20 cm (20 1/2" -30")
Joining process:	Two sided simultaneous multi-process arc welding
Joint design:	Horizontal fillet
No. of stiffeners welded simultaneously:	4

Cross Beam Stiffeners

Maximum length:	15.85 meters (52' -0")
Flange width range:	35.56-76.20 cm (14" -30")
Web width range (height):	15.24-243.84 cm (6" -96")
Maximum weight:	4662.5 kg (12,500 Lbs.)
Cross beam spacing:	30.48-152.40 cm (12" -60")
Joining process:	Manual flux cored Gas Metal Arc Welding (GMAW)

Completed Panel

Panel weight density range:	.84-8.4 kg/sq.mt. (20 - 200 Lbs/Sq.Ft.)
-----------------------------	--------------------------------------------

Site Location

Site location presented a unique problem in that a 182.88 m x 19.82 m (600' x 65') envelope not already in use, with accessible crane service, that could be supplied material from the rest of the yard, seemed unavailable.

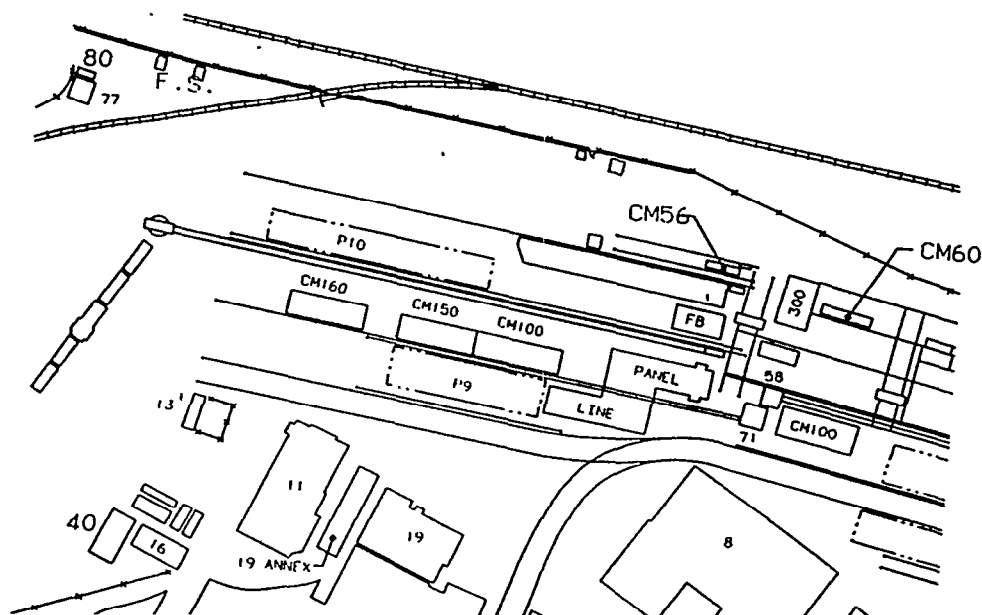


Fig. 2 Proposed site -- existing

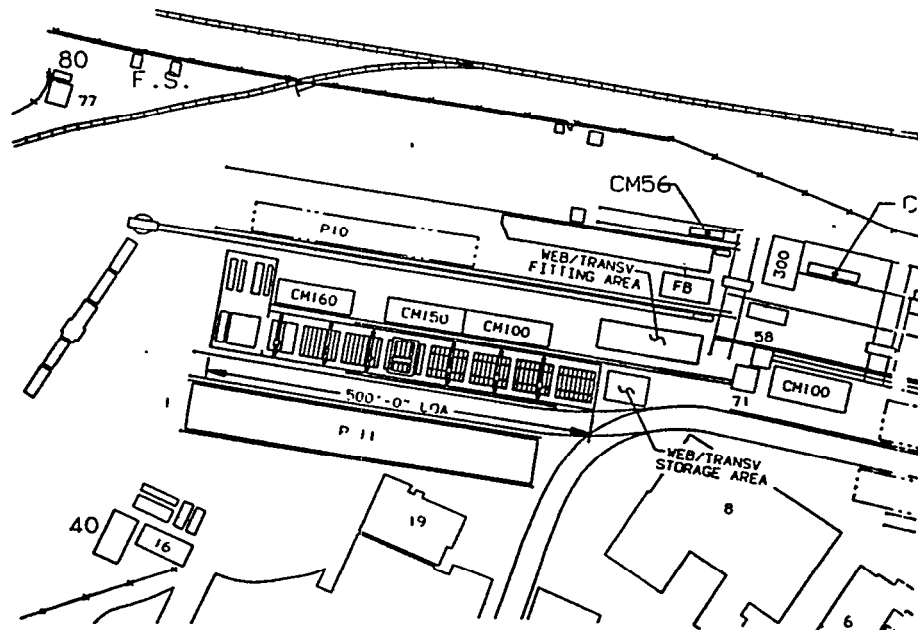


Fig. 3 Proposed site - facilities requirements

A site was chosen by eliminating alternatives that presented complicated obstacles inherent in the areas such as:

- . The need to reroute the Direct Numerical Control (DNC) for burning machines;
- . Retracking for crane service; and
- . Problems with transportation of material.

Plate Delivery

Creative thinking was required in regard to a number of other issues from a list that seemed to grow. A significant issue was how to get the plates to be paneled from the adjacent storage area to the fitting station. A transfer car, that could be loaded by an existing magnetic crane and then translated to the feed side of the panel line and convey the plate into the fitting station, resolved the problem. Additionally, the transfer car would double as a platen extension when required.

Selection of a One Side Welding (OSW) System

To compensate for the declining number of skilled welders, while continuing to reduce hours by minimizing material handling equipment, setup, and facility requirements, has been the forte of one side welding for many years. However, experience has shown that one side welding has introduced other variables that quite often counteract the original objectives, such as:

- . Joint preparations require more exactness;
- . Thinner plates not requiring a beveled preparation on two-side welds now require them;
- . Consumable quantities are increased;
- . Equipment operating parameter ranges become narrow; and
- . A highly skilled (trained by trial and error) operator is needed more so now than ever.

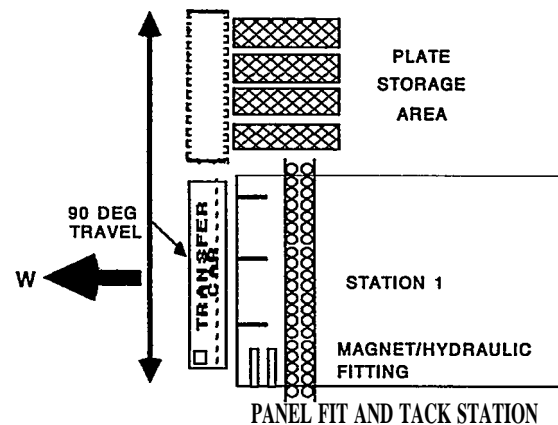


Fig. 4 Transfer car at head of panel fit and tack station

The alternatives to the aforementioned were to struggle through with an inefficient system or continue two-side welds. Support for successful OSW abounds in

foreign and domestic yards, such that acceptance of a system that is not completely cost effective could not be viewed as an alternative. Hence, the goal would be to avoid areas even marginally efficient and focus on areas that further development would enhance.

The development of NASSCO's OSW system had the ultra success of some systems, the complete failure of others and, possibly worse, the burden of those not operating efficiently, before being selected. Should cost studies be done, they would reveal that the cost of weld repair, increased joint preparation, greater care in fit-up, increased consumables, and the replacement of damaged copper bars, would exceed the cost of two-side welding.

Avoiding this would be the prime directive in developing the OSW station. The operating characteristics most sought after were determined strongly by the operation of known OSW systems as well as areas that would be enhanced by further development. The desired characteristics are:

- . One pass, OSW with conventional tandem electrodes;
- . Reduction in edge preparations;
- . Low volume of welding consumables;
- . Tolerance of joint variations;
- . Welding of pre-fitted, pre-tacked panels;
- . Reduced operator complications;
- . Minimal distortion; and
- . Consistently meeting visual Destructive Testing (DT) and Nondestructive Testing (NDT) requirements.

Typically, one pass OSW requires a multi-wire (2-3) and/or iron powder additive for most plate thicknesses. Inasmuch as mixing iron powder with conventional flux is somewhat of a black art, and obtaining some of the foreign premixed iron powder fluxes in the U.S. is difficult, many yards are using multi-wire, multi-pass, one side welding processes.

The initial decision for the OSW was the selection of either a direct current, alternating current, or series arc OSW system. After a 6-month evaluation of OSW systems, no one system, at least in its entirety, was selected. The decision was made to incorporate similarities in the three which will be referred to throughout the body of this paper as oscillating DC-AC OSW.

For process approval it was first necessary to develop a full scale working prototype of the intended

system with the required features. Secondly, proof was needed that the system could consistently produce welds visually and radiographically acceptable. After these tests were confirmed, further tests were performed on high yield steels that would be sensitive to higher heat inputs from OSW.

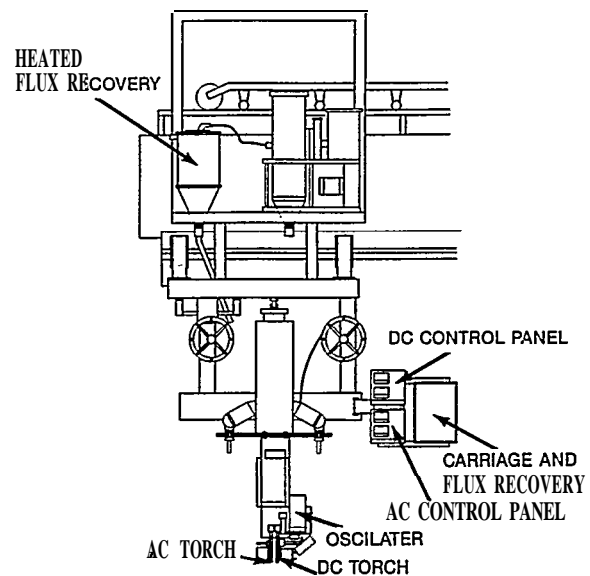


Fig. 5 Welding carriage

Procedural qualification was undertaken on the prototype manufactured in Indiana. To prove the concept, a series of tests were done simulating production conditions for plate thicknesses and joint designs. The earliest possible acceptance of these tests and the need for further training and parameter development were sufficient justification for setting up another test fixture in the shipyard. Though crude in appearance, the experience gained from these welds proved to be de cornerstone for the cause and effect operational knowledge as well as developing a level of confidence in operating the equipment.

All aspects of the acceptance criteria of both military (MIL-STD-248C) and commercial (ASME Section IX) standards were under constant scrutiny. The visual being the first level of inspection, followed by Radiographic, Ultrasonic, and mechanical tests.

The visual appearance of the welds provided information for parameter adjustments for corrections Of:

- . Reinforcement
- . Bead shape
- . Distortion.

Radiographic and ultrasonic tests were performed on all visually acceptable test welds and evaluated by a Level III Nondestructive Test Inspector. After acceptance of nondestructive testing, coupons were prepared for the various mechanical tests for ductility, tensile, and toughness. Figure 6 is the actual procedural qualification test report for the Oscillating DC-AC SAW on DH 36 material to the American Bureau of Shipping Standards.

ENGINEERING SERVICES AND INSPECTION
1165 WALNUT AVENUE, SUITE #4
CHULA VISTA, CALIFORNIA 92011
(619) 575-5012

MECHANICAL TEST REPORT
(WELDING PROCEDURE QUALIFICATION)

DATE: 28 MAY 91 EST JOB #: 1511-21 CUSTOMER: NASCO P.O. #: MC 178593-S
WELDER: WELD PROCEDURE #: NF-742.2 WELD PROCESS: SAW-PA POSITION: FLAT
BASE MATERIAL SPECIFICATION: MIL-E-216216 (1750° HY-80 PLATE)
FILLER MATERIAL SPECIFICATION: MIL-C-21765/4 (LINCOLN 70/761) SIZE: 1/8" & 5/32"

TEST #	LENGTH INCHES	WIDTH INCHES	DIA-WEIDER INCHES	SQUARE AREA INCHES	TENSILE LOAD POUNDS	TENSILE STRENGTH PSI	YIELD LOAD POUNDS	YIELD STRENGTH PSI	ELONG-ACTION PERCENT	FAIL STATE	RE-SULTS
TR-1	1.006"	0.770"	N/A	0.7746	90,150	116,383	N/A	N/A	N/A	BASE	N/A
TR-2	0.995"	0.769"	N/A	0.7652	89,400	116,832	N/A	N/A	N/A	BASE	N/A
AN-1	N/A	N/A	0.507"	0.2019	23,900	118,375	21,700	107,479	22.07%		SAT

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MECHANICAL TEST REPORT
(WELDING PROCEDURE QUALIFICATION)

DATE: 14 SEPTEMBER 90 EST JOB #: 1497-20
CUSTOMER: NASCO P.O. ORDER #: MC 168102-S
WELDER: UNKNOWN WELDER ID:
WELD PROCEDURE #: XS-65-1 WELD PROCESS: GMAW POSITION: 1G
BASE MATERIAL SPECIFICATION: MIL-E-16216 (1750° HY-80 PLATE)
FILLER MATERIAL SPECIFICATION: MIL-C-21765/2 (MIL-100S-1) SIZE: 5/32"

TEST #	LENGTH INCHES	WIDTH INCHES	DIA-WEIDER INCHES	SQUARE AREA INCHES	TENSILE LOAD POUNDS	TENSILE STRENGTH PSI	YIELD LOAD POUNDS	YIELD STRENGTH PSI	ELONG-ACTION PERCENT	FAIL STATE	RE-SULTS
TR-1	1.006"	0.770"	N/A	0.7746	90,150	116,383	N/A	N/A	N/A	BASE	N/A
TR-2	0.995"	0.769"	N/A	0.7652	89,400	116,832	N/A	N/A	N/A	BASE	N/A
AN-1	N/A	N/A	0.507"	0.2019	23,900	118,375	21,700	107,479	22.07%		SAT

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MECHANICAL TEST REPORT
(WELDING PROCEDURE QUALIFICATION)

DATE: 14 SEPTEMBER 90 EST JOB #: 1496-20
CUSTOMER: NASCO P.O. ORDER #: MC 168102-S
WELDER: UNKNOWN WELDER ID:
WELD PROCEDURE #: XS-75-1 WELD PROCESS: GMAW POSITION: 1G
BASE MATERIAL SPECIFICATION: MIL-E-16216 (1750° HY-80 PLATE)
FILLER MATERIAL SPECIFICATION: MIL-C-21765/2 (MIL-100S-1) SIZE: 5/32"

TEST #	LENGTH INCHES	WIDTH INCHES	DIA-WEIDER INCHES	SQUARE AREA INCHES	TENSILE LOAD POUNDS	TENSILE STRENGTH PSI	YIELD LOAD POUNDS	YIELD STRENGTH PSI	ELONG-ACTION PERCENT	FAIL STATE	RE-SULTS
TR-1	0.990"	0.757"	N/A	0.7494	87,300	116,493	N/A	N/A	N/A	BASE	N/A
TR-2	0.994"	0.760"	N/A	0.7554	88,600	117,282	N/A	N/A	N/A	BASE	N/A
AN-1	N/A	N/A	0.498"	0.1548	22,500	116,530	21,000	107,800	18.75%		SAT

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MECHANICAL TEST REPORT
(WELDING PROCEDURE QUALIFICATION)

DATE: 14 SEPTEMBER 90 EST JOB #: 1501-20
CUSTOMER: NASCO P.O. ORDER #: MC 168310-S
WELDER: UNKNOWN WELDER ID:
WELD PROCEDURE #: XS-82-1 WELD PROCESS: GMAW POSITION: 1G
BASE MATERIAL SPECIFICATION: MIL-E-16216 (1750° HY-80 PLATE)
FILLER MATERIAL SPECIFICATION: MIL-C-21765/2 (MIL-100S-1) SIZE: 5/32"

TEST #	LENGTH INCHES	WIDTH INCHES	DIA-WEIDER INCHES	SQUARE AREA INCHES	TENSILE LOAD POUNDS	TENSILE STRENGTH PSI	YIELD LOAD POUNDS	YIELD STRENGTH PSI	ELONG-ACTION PERCENT	FAIL STATE	RE-SULTS
TR-1	0.997"	0.725"	N/A	0.7228	86,500	119,673	N/A	N/A	N/A	BASE	N/A
TR-2	0.994"	0.715"	N/A	0.7107	87,100	122,555	N/A	N/A	N/A	BASE	N/A
AN-1	N/A	N/A	0.501"	0.1973	22,500	114,155	19,200	97,412	22.65%		SAT

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(619) 575-5012

MECHANICAL TEST REPORT
(WELDING PROCEDURE QUALIFICATION)

DATE: 14 SEPTEMBER 90 EST JOB #: 1511-20
CUSTOMER: NASCO P.O. ORDER #: MC 168311-S
WELDER: UNKNOWN WELDER ID:
WELD PROCEDURE #: XS-92-1 WELD PROCESS: GMAW POSITION: 1G
BASE MATERIAL SPECIFICATION: MIL-E-16216 (1750° HY-80 PLATE)
FILLER MATERIAL SPECIFICATION: MIL-C-21765/2 (MIL-100S-1) SIZE: 5/32"

TEST #	LENGTH INCHES	WIDTH INCHES	DIA-WEIDER INCHES	SQUARE AREA INCHES	TENSILE LOAD POUNDS	TENSILE STRENGTH PSI	YIELD LOAD POUNDS	YIELD STRENGTH PSI	ELONG-ACTION PERCENT	FAIL STATE	RE-SULTS
TR-1	0.991"	0.715"	N/A	0.7086	85,400	120,519	N/A	N/A	N/A	BASE	N/A
TR-2	0.997"	0.720"	N/A	0.7178	85,800	119,532	N/A	N/A	N/A	BASE	N/A
AN-1	N/A	N/A	0.371"	0.1081	13,100	121,181	10,600	98,055	16.31%		SAT

GUIDED-BEND TESTS

TYPE	MINOR RADIUS	SPECIMEN WIDTH	MATERIAL THICKNESS	RESULTS
SIDE 1	.8125"	0.375"	.750"	ACCEPTABLE
SIDE 2	.8125"	0.375"	.750"	ACCEPTABLE

CHARPY IMPACT TESTS

SPECIMEN NUMBER	IMPACT STRENGTH REQUIRED	IMPACT STRENGTH ACHIEVED	TEST TEMPERATURE	RESULTS
#1	35.00 FT LBS	56.00 FT LBS	-60°F	SAT
#2	35.00 FT LBS	57.00 FT LBS	-60°F	SAT
#3	35.00 FT LBS	55.00 FT LBS	-60°F	SAT

AVERAGE IMPACT STRENGTH: 56.0 FT LBS

THE ABOVE TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM A-370, ASTM E-23, ASTM E-190, MIL-STD-2480, ANSI/ASME B4.0-85, ANSI/ASME D1.1-90 & ASME BOILER & PRESSURE VESSEL CODE SECTION IX.

LAB TECHNICIAN: JIM HAN ASST LEVEL III RM-907/ANS CHL #42052041

Fig. 7 High Heat Input Procedures

TYPE	MINOR RADIUS	SPECIMEN WIDTH	MATERIAL THICKNESS	RESULTS
SIDE 1	.8125"	0.375"	.750"	ACCEPTABLE
SIDE 2	.8125"	0.375"	.750"	ACCEPTABLE
SIDE 3	.8125"	0.375"	.750"	ACCEPTABLE
SIDE 4	.8125"	0.375"	.750"	ACCEPTABLE

SPECIMEN NUMBER	IMPACT STRENGTH REQUIRED	IMPACT STRENGTH ACHIEVED	TEST TEMPERATURE	RESULTS
WELD 1	17.00 FT LBS	33.0 FT LBS	-40°F	SAT
WELD 2	17.00 FT LBS	30.0 FT LBS	-40°F	SAT
WELD 3	17.00 FT LBS	36.5 FT LBS	-40°F	SAT
FUSION LINE (F/T)	17.00 FT LBS	33.0 FT LBS	-40°F	SAT
FUSION LINE (F/T)	17.00 FT LBS	32.0 FT LBS	-40°F	SAT
FUSION LINE (F/T)	17.00 FT LBS	29.0 FT LBS	-40°F	SAT

THE ABOVE TESTS WERE PERFORMED IN ACCORDANCE WITH ASTM A-370, ASTM E-23, ASTM E-190, MIL-STD-2480, ANSI/ASME B4.0-85, ANSI/ASME D1.1-90, ASME RULES & ASME B & P V C SECTION IX.

LAB TECHNICIAN: JIM HAN ASST LEVEL III RM-907/ANS CHL #42052041

Fig. 6 Procedural Qualification Report

Process Sensitive High Yield Steels

A common problem with all OSW processes for military applications is the heat input limitation of 2165 KJ/m (55KJ/in.) for 13 mm (1/2 inch) and thicker and 1772/m (45KJ/m) for less than 13 mm (1/2 inch) plates.

Anticipating the Oscillating DC-AC SAW would be no different in terms of exceeding this limitation, high heat input procedures were developed for 2558 KJ/m (65 KJ/in.), 2952 KJ/m (75 KJ/in.), 3346 KJ/m (85 KJ/in.), 3739 KJ/m (95 KJ/in.), and submitted to NAVSEA.

The results of these tests and knowledge of similar results from other shipyards causes the writer to conclude that the aforementioned heat input restrictions are no longer valid and should be modified.

CHARACTERISTICS OF OSCILLATING DC-AC ONE SIDE WELDING

One Pass One Side Welding

The characteristics of Oscillating DC-AC welding permits one side, one pass welding of plates with thicknesses up to 20 mm (3/4") with:

- . Two small diameter wires;
- . Lower heat inputs;
- . Conventional SAW wire arrangement and current;
- . Minimal edge preparations;
- . Narrow root openings; and
- . No iron powder additives for fill.

The absence of additives for joint fill, critical wire straightening requirements, extensive joint preparations, large root openings, or special welding currents does much in reducing the complications in one side welding. At the very least, the list of variables for an unforgiving process has been shortened. Production use is further enhanced with Oscillating DC-AC SAW by:

- . Greater tolerance to production joint variations;
- . Increased deposition rates;
- . A welded back-bead look; and
- . Reduced user complication.

Reductions in Edge Preparations

The joint designs for one side welding generally are double "V" preparations from 45° to 60° included angles for plate thickness greater than 6 mm (1/4 inch). Root openings vary, but range from 0 to .64 cm (1/4 inch). Two-side welding, however, is done with 16 mm (5/8 inch) square edge preparation and 20 mm (3/4 inch) is not uncommon in some foreign yards. Oscillating DC-AC was selected because there would be minimal change in the edge preparation requirement. Yard standard practice was not beveling mild steel plates 16 mm (5/8 inch) and below and double beveling plates greater than 16 mm (5/8 inch) for all two-side welds. This was altered only slightly when changing to the one side welding operation. Plates with $t \leq 15$ mm (9/16 inch) remained square edge preparation and plates $t \geq 16$ mm (5/8 inch) would require a 45° included with 6 mm (1/4 inch) land.

These two joint designs did much in keeping the changes for edge preparation requirements to a minimum when the new instructions were given to engineering.

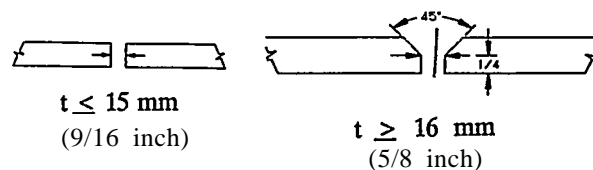


Fig. 8 Edge Preparation Requirements

Reductions in Consumable Usage

The controlling factor in welding cost is reducing the weight of weld metal required. Most of the other associated costs are related to this factor, including:

- . Less time required to deposit;
- . Fewer machines;
- . Fewer replacement parts;
- . Lower maintenance costs;
- . Less energy; and
- . Reduced consumables.

The most straightforward manner by which the volume of deposited weld metal can be reduced is to reduce the cross-sectional area of the weld area by changing the geometry of the joint design

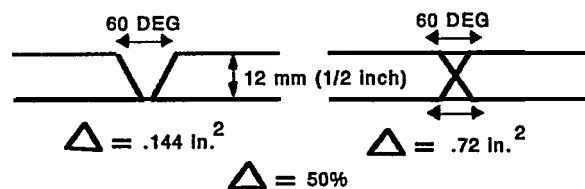


Fig. 9 Effect of cross sectional area on
fill requirements

However, the joint design for OSW is critical in all of the Flux Copper Backing (FCB) systems. Adjusting any part, i.e., root opening, including angle or land, to reduce the weld metal required would mean sacrificing the effectiveness of the system of which the joint design is a part.

Taking the extreme conditions of 16 mm (5/8 inch) plate with a 60° included angle for OSW and 16 mm (5/8 inch) plate with a square edge preparation for two side welding (1.6 mm [1/16 inch] root opening for comparison only), Figure 10 shows that there is an approximate 50% increase in weld metal over the two-side weld.

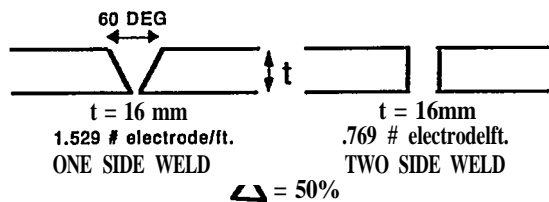


Fig. 10 Weld metal requirement for OSW compared to two-side welding

Hence, for an OSW system to be cost effective, consideration must be given to the increased volume of weld metal required. It should also be noted that plates 12 mm (1/2 inch) and below, requiring bevels for other OSW systems, were prone to heat induced distortion which increased fitting time and reduced the quality of the bevel.

The Oscillating DC-AC was chosen over other OSW systems because there was a significant reduction in the volume of weld metal as a result of joint requirement (approximately 50% less weld metal required). Should series arc rather than direct SAW be used in the comparison, the percentage would be higher because of the increased root opening.

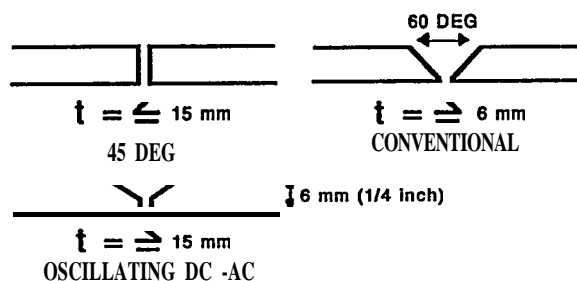


Fig 11. OSW Comparison

Joint Fit-UD Variations

Even with a number of process controls, fit-up variations are at best kept minimal. Recognized as a nuisance with any other welding operation, even minor variations in joint fit-up spell failure for OSW. If weld repair was not enough, add to this the repair or replacement cost of the copper bar with the task of separating the copper bar from the plate, and there will be strong arguments for two-side welds.

Many variables affect the amount of fit-up variation an OSW system can tolerate such as:

- . Root Opening;
- . Included Angle; and
- . Plate Fairness.

The Oscillating DC-AC OSW has proven to be more tolerable to production fit-ups. However, the tighter the controls for fit-up deviations, as with any OSW system, the better the results.

Excessively long deviations in root openings require a seal bead. If care is taken in making the seal weld, repair of the second side is generally not necessary or noticeable.

With operator practice, travel speed adjustments prove equally beneficial. This method requires that the operator inspect the seam prior to welding for deviations greater than the allowable and mark their length. If the deviation is noticeably greater, a reduction in the travel speed will prevent the burn through; if narrower an increase will permit greater penetration. An exact increase or decrease has not been possible to determine, but even slight changes have proven to be effective.

Uniform Shrinkage Information

Reduction in the volume of weld metal required, deposited with small diameter electrodes and definitive parameter information makes weld shrinkage information very predictable because of the repeating variables. To produce neat panels this information is vital. Once installed and fully operational, the excess material plan, will be incorporated in Direct Numerical Control burning information to account for transverse weld shrinkage from the OSW station.

SPECIAL FEATURES OF THE LINE

Fitting Plates of Unequal Thickness with the Stiffener Side Up

Plates to be paneled are fed onto the line from the burning machines adjacent to the panel line by a plate transfer car. The transfer car leaves the plate staging area and is positioned at the head of the panel line. The plate is then conveyed over the variable height magnetic fitting bed. The panel fitting station is a special feature of the line which enables the automatic positioning of plates having unequal thickness with the stiffener side up.

The fitting bed includes the following features. It:

- . Ensures total conveyerized panel flow;
- . Eliminates interruptions due to panel turnover;
- . Positions with variable height magnetic beds with hydraulic lifting rams; and
- . Accommodates panel seams having unequal thicknesses with stiffener side up.

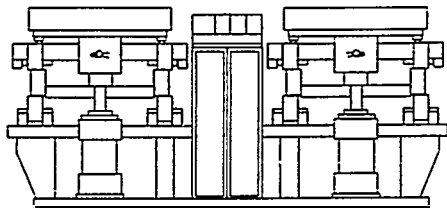


Fig. 12 Panel fitting station

Pre-Fitted (Tacked) Full Size Panels

Pre-fitting the panels prior to OSW was selected in lieu of fitting and welding at the same station. This allows a better balance of work per station. It also eliminates the interruption of panels that have to be faired and tacked because of handling or heat-induced distortion that the OSW holddown would not remove. Especially disruptive was that this work usually disturbed the flux bed so that it had to be redone or increase the risk of damaging the copper bar. It was found that the latter's disruption had no equal in causing lost time. However, pre-fitted panels would require either tie plates or tack welding, approximately 40 tie plates per seam. The additional operation of removing the tie plates, grinding the tacks, and projectiles from the abrasive wheel caused excessive rework and production interferences. To eliminate this, procedures were developed using the Oscillating DC-AC process to weld through tacks. To safeguard against the negative effects of the tacks on weld quality, measures that proved effective within the welding parameter ranges for the procedure were:

- . Reduced electrical stick-out on DC wire;
- . Lower voltage;
- . Smaller diameter lead wire;
- . The use of GMAW for the tacks; and
- . Drag angle on DC torch.

In addition, greater care was also directed toward the tacking operation which included:

- . Location plan;
- . Quality;
- . Size;
- . Number; and
- . Process used.

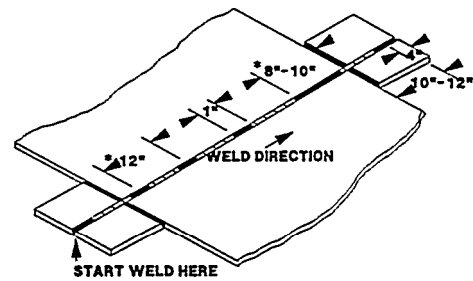


Fig. 13 Guidelines for tack location

Shipfitters that were selected to prepare panels for OSW were trained with FCAW as well as the requirements of the fitting operation. This measure should be ranked in equal standing with the aforementioned.

Weld Plates of Unequal Thickness With Stiffener Side up

The ability to weld plates of unequal thickness with the stiffener side up is a patented feature of the OSW station. The floating cradle for the FCB will uniformly adjust to back side surfaces having either a square or chamfered transition in the joining plates. This operation includes a variable pressure lift system for FCB contact to plate and weld pressure.

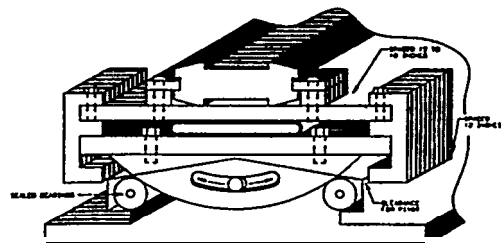


Fig. 14 Floating cradle for FCB welds with plates of unequal thickness

Longitudinal Attachment

~~Materials~~ Materials delivery problems continued with regard to how longitudinals were supplied to the welded plate panels after seam welding. Loading adjacent to the line was ruled out in favor of kitting the longitudinals at the head of the line in special racks (Figure 15) that would hold the shift's requirement for stiffeners.

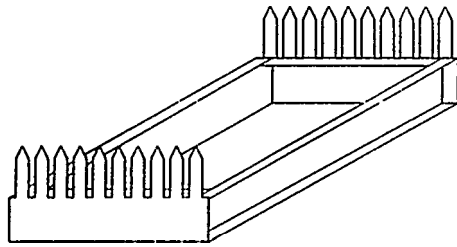


Fig. 15 Stiffener Rack

Location. The overhead crane rails were extended to enhance the panel line's independence from the yard's whirley cranes. The rack of stiffeners could be lifted from the storage area and positioned just after the welding station on a special foundation that allowed the panels to be conveyed under it into the layout station. (Figure 16) Once laid out, the stiffener would be set in place with a 10-ton magnetic crane. Roughly positioned, the panel would then be conveyed into the stiffener fitting area.

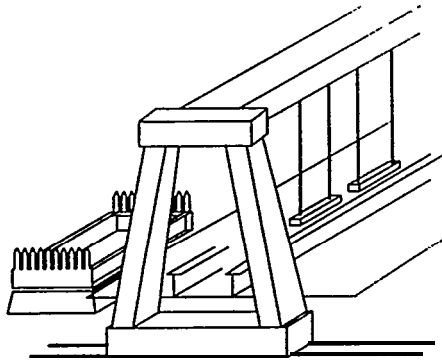


Fig. 16 Stiffener placement on panel

Stiffener Fitting

The problem of automatic fitting longitudinals that were not parallel with the panels, and the ability to fit stiffeners that were skewed on the panel, was addressed by developing a track mounted multi-hydraulic ram that could be skewed to match the stiffener.

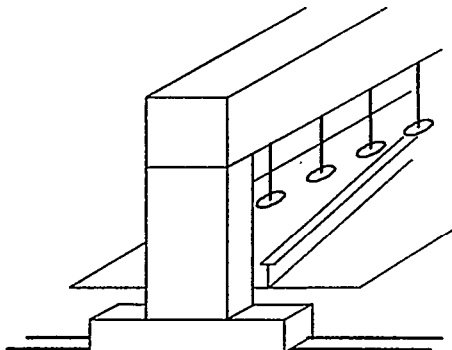


Fig. 17 Stiffener fitter

Welding

Variable stiffener spacing is common with non-series ship production and presents a problem with equipment setup for multi-torch automatic welding equipment. To minimize time lost due to equipment setup, the automatic stiffener welder was designed with floating heads that would adjust to virtually any stiffener spacing automatically with up to three feet of skew. This feature would allow different spacings from one panel to the next. It would also allow different spacing on the same panel for simultaneous welding of four longitudinals or joining smaller panels with fewer stiffeners. Thus, a greater versatility was realized while keeping the tasks repetitive without undue dependence on skilled labor for non-welding related tasks.

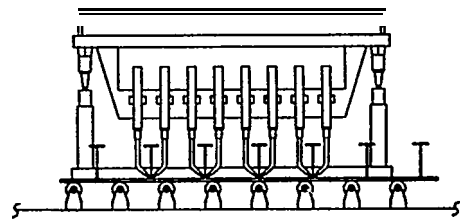


Fig. 18 Multiple head stiffener welder

SPECIAL OPERATIONAL ENHANCEMENTS

On-Site Repair of Copper Bar

Even when seemingly all precautions were taken to prevent burn through to the copper bar, it became more practical to minimize burn through rather than trying to eliminate it. Allowing that an occasional burn through is unavoidable, repair of the copper bar is a must to ensure the back bead's uniform shape. The cost of replacement bars, even on a small test bed, soon became an issue. Removing the copper bar was so time consuming that an on-site repair procedure was necessary. Though welding copper is not a feat in itself, the procedure included:

- . A semi-automatic process;
- . Minimizing distortion;
- . Avoiding excessive build-up; and
- . Ease of reshaping bar.

Though a procedure was developed to use Tungsten Inert Gas (TIG), it required too long even for minor repairs. The semi-automatic process provided favorable results as long as all oxidation was removed, and a specific preheat was reached before welding.

Welding Parameter Sheets

The need for clear and well defined welding parameters is important for any welding process; however, for OSW it was proven to be the determining factor for a successful one-side system. To ensure that repeatability would be possible, Weld Engineering first researched all seams that would be welded using the one-side system and made test welds for proper parameter ranges. These parameter sheets (Figure 19) were developed for all welds which required a change in any essential variables as a result of:

- . Plate thickness;
- . Edge preparation;
- . Unequal thickness; or
- . Chamfered plate.

Any weld with a significant change in voltage, amperage or travel speed was assigned a parameter number and given to the operator with all necessary equipment settings.

GROWTH OR EXPANSION ITEMS

Special Purpose Flux FCB Welding

During several trips to foreign shipyards, it was apparent that a great deal of research had been devoted to developing products especially formulated for FCB welding. It was noted that these products, particularly the fluxes, had better performance characteristics than those of some of the domestic fluxes available for the same purpose. The availability of these fluxes in the U.S. is marginal (some of which are not offered) and usually have long lead times with heavy import duties. It is the intent of NASSCO Weld Engineering to propose a panel project that would support a joint venture with an American welding consumable manufacturer to develop a special line of FCB-related products. The performance characteristics would be targeted to:

- . Increase tolerance to joint variations;
- . Offer greater support to the weld pool for high amperage welds;
- . Protect the copper bar from burn through; and
- . Enhance FCB welding with portable equipment in other areas.

IDENTIFICATION

PANEL LINE PARAMETER
NO. _____

OPERATOR _____ FOREMAN _____ SHIFT _____

JOINT DESIGN

PARAMETERS

PASS NO.	DC-AC	EXPR	TENSE	ARC	AMP	TRAVEL	TIG	TIG	TIG	TIG	TIG	TIG	TIG

COMMENTS

IDENTIFICATION

PANEL LINE PARAMETER
NO. _____

OPERATOR _____ FOREMAN _____ SHIFT _____

JOINT DESIGN

PARAMETERS

PASS NO.	DC-AC	EXPR	TENSE	ARC	AMP	TRAVEL	TIG	TIG	TIG	TIG	TIG	TIG	TIG

COMMENTS

Fig. 19 Welding parameter sheets

All products would be tested to normal shipyard building practices with similar equipment. The results would be documented as to the ability to consistently meet Radiographic Testing (RT) and mechanical requirements of regulatory bodies.

CONCLUSION

After months of feasibility studies, specifications for prototypes and revisions incorporated into the production equipment, operational enhancements are ongoing; more so in the area of OSW. To date the OSW has proved to be more cost effective in the plate thickness range of 6mm (1/4 inch) to 20 mm (3/4 inch). There has been minimal repair to underside welds and the NDT reject rate has been exceptionally low.

At this writing, further consideration is being given to the cost effectiveness of OSW in relation to plate thickness. Successive panels requiring multiple pass for fill at the OSW station interrupts material flow, which results in frequent manpower adjustments at the adjoining station. Though the welds are of equal quality, the additional time per seam (approximately 45 minutes for 15.8 m [52 feet]) is a major concern for four seam panels. A four seam panel usually requiring three

hours of arc time could require nine hours. Methods to correct this are:

1. Heavy plate to be welded on second and third Shift.
2. Additional electrodes for fill.
3. A separate OSW station.
4. Portable SAW for fill after OSW pass.
5. Eliminate OSW for panels one inch thick and greater.

The impact will vary from contract to contract but at this writing, items one and four above are proving to be effective.

ACKNOWLEDGMENT

The author wishes to credit the following people and organizations as having a major role in the success of this project: West Henry, Jr., Susan Olson, Andy Parikh, Sergio Escobedo, Keith Londot, NASSCO Weld Engineering, Facilities, Maintenance, and Steel departments, and Ogden Engineering.



Intelligent Automated Welding for Shipyard Applications

IIB-2

S. Madden, Visitor, **H.H. Vanderveldt**, Visitor and **J. Jones**, Visitor, American Welding Institute

ABSTRACT

Computer Aided Process Planning (CAPP) integrated with Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) will form the basis of engineering/planning systems of the future. These systems will have the capability to operate in a paperless environment and provide highly optimized process operation plans. The WELDEXCELL System is a prototype of such a system for welding in shipyards. The paper discusses three significant computer technology advances which have been incorporated into the WELDEXCELL prototype. First is a computerized system for allowing multiple knowledge sources (expert systems, humans, data systems, etc.) to work together to solve a common problem (the weld plan). This system is called a "blackboard". The second is a methodology for the blackboard to communicate to the human user. This interface includes full interactive graphics fully integrated to CAD as well as datasearches and automatic completion of routine engineering tasks. The third is artificial neural networks (ANS's), which are based on biological neural networks (e.g. the human brain), that can do neural reasoning tasks about difficult problems. ANS's offer the opportunity to model highly complex multi-variable and non-linear processes (e.g. welding) and provide a means for an engineer to quantitatively assess the process and its operation.

GLOSSARY OF ACRONYMS

ANSI	American National Standards Institute
ANS	Artificial Neural Networks
ASTM	American Society for Testing and Materials
AWI	American Welding Institute
AWS	American Welding Society
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAPP	Computer Aided Process Planning
CNC	Computer Numerical Control
D-A Net	Delta-Activity™ Network
DOS	Disk Operating System
DXF	File format used by AutoCad™

FCAW Flux Cored Arc Welding
IGES Initial Graphics Exchange Specification
PSNS Puget Sound Naval Ship Yard
WELDEXCELL WELDing Expert manufacturing CELL
WELDSCHED Weld Schedule Expert System
WJC Welding Job Controller
WJP Welding Job Planner
WPS Welding Procedure Specification

INTRODUCTION

The joining of metals into fabricated components and structures is a difficult task. The most common method of joining metals is welding, but the welding process is complex and requires several important steps to be performed in a carefully integrated manner. The weld joint is first designed and engineered properly, then that design must be correctly communicated to the fabrication facility. The appropriate welding consumables, including filler metal and protective flux or inert gas, are chosen. Then the welding procedure is specified, including preheating schedules; welding parameters such as voltage, current and travel speed; and, postweld heat treating. Finally, the weld must be performed under highly skilled human guidance and control. A minor error in any of these steps, if undetected, can create an unsuitable welded component, which in later use may result in a catastrophic failure and perhaps loss of life.

An extremely complex and interrelated system of codes, specifications, tests, and inspections ensures that the vast majority of welds will never fail in service. A weld, which is a small bit of solidified metal, is expected to have the same (or perhaps better) properties as the base metal that it joins. The base metal may have undergone hours of careful and expensive heat treating and processing, yet the weld must be as corrosion resistant, as strong, as ductile, and as fracture resistant as the base metal. But the weld does not have the advantage of all of that processing.

Fortunately, a large number of engineers, designers, and welders work within the system of codes and specifications to ensure the high quality of welded joints, but this system is very expensive and requires the careful attention of many human experts. As the availability of engineering talent in the United States continues to decrease over the next decade, Computer Aided Engineering (CAE) will take on added importance. Consequently, welding engineering and planning is an ideal application for artificial intelligence technology including expert systems. However, no single expert system could be expected to perform the myriad of tasks required to make a welded joint. For example, there are over 100 welding processes ranging from simple flame heating to exotic laser welding; there are several hundred welding filler metals -- from plane carbon steel to elaborate chemical mixtures of alloying ingredients; and there are over 1000 different grades of steel classified by the American Society for Testing and Materials (ASTM) that may have to be joined. The possible combinations of welding process, filler metal, and steel base metal would number into the millions.

The solution to this problem is a system being developed for the United States Navy called WELDEXCELL. The test prototype of WELDEXCELL was delivered to Puget Sound Naval Ship Yard (PSNS) for testing during the summer of 1991. The expert systems needed for welding include materials selection, joint design, welding process and procedure selection. There is a standard Computer Aided Design (CAD) system interface to draw the design and communicate that design to the shop floor as well as a CAD interface to the robot path planner.

The system also includes intelligent processing to control a complex automated welding system or robot with an array of sensors to guide it and to provide feedback for process control. The system actually being delivered to the Navy will be configured with at least two sensors, but the system is capable of operating in a multiple sensor environment.

The American Welding Institute (AWI), together with its partners, the Colorado School of Mines and MTS Systems, Inc., is developing this intelligent weld process planner and intelligent control system for flexible welded fabrication known as the WELDing Expert manufacturing CELL (WELDEXCELL). This project has entailed development of a series of linked expert systems acting as a computer aided engineering and planning assistant and software to download welding plans and procedures to a welding system and automated manipulator or robot for automatic execution. An intelligent welding control system is being completed which will interface to a robot system, a series of sensors, and to the welding equipment. This paper contains a general description of the system and examples of the operation of the prototype engineering/planning workstation and user interface.

SYSTEM OVERVIEW

The WELDEXCELL System is logically divided into two major subsystems: the Welding Job Planner (WJP) and the Welding Job Controller (WJC). Figure 1 is a conceptual schematic of the WELDEXCELL System.

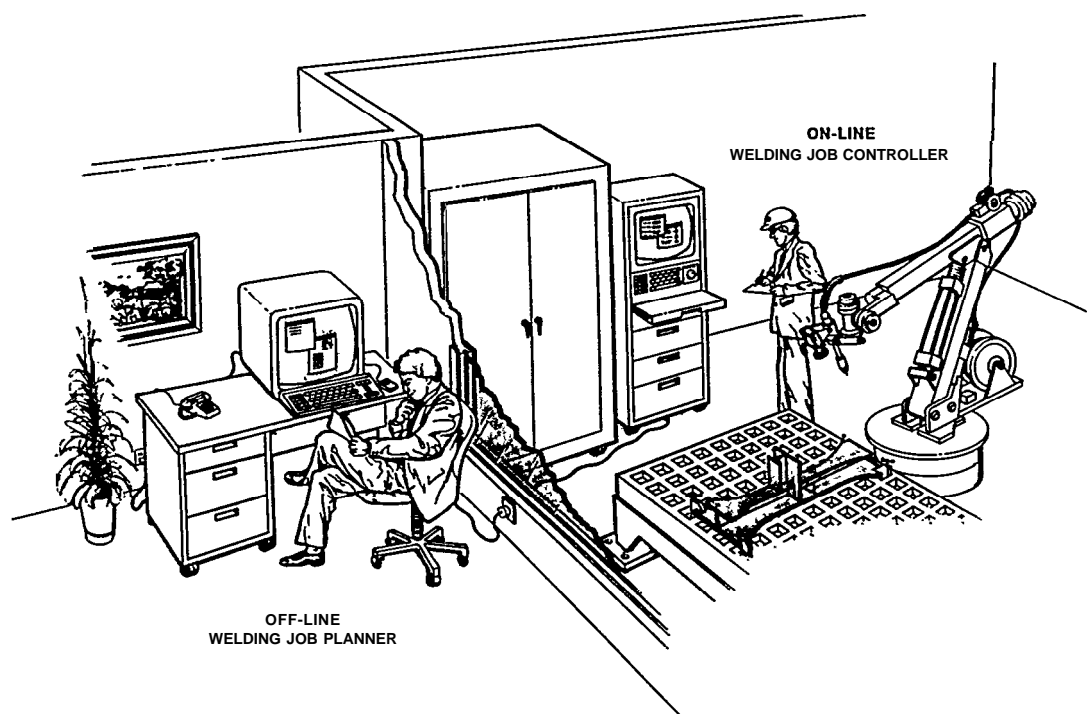


Figure 1

A high-level block diagram is shown in figure 2.

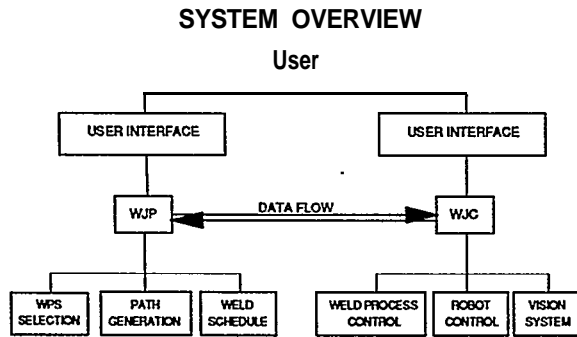


Figure 2

The Welding Job Planner is responsible for helping the welding engineer design and set up a weld path (for the robot or automated system) coupled with a welding schedule (specific procedure for shop floor implementation). The WJP is comprised of several expert systems, each contributing to the design of the particular weld. A software architecture known as a blackboard system is used to manage the interactions of the multiple expert systems. The blackboard architecture is a powerful and flexible software tool for mediating the contributions of several knowledge sources. It is described in detail later in the paper.

The blackboard system uses various expert systems, knowledge bases and databases, and a control scheme (usually implemented as another expert system) with the goal of moving the system toward a solution to solve complex problems. In this implementation, the blackboard will also be able to ask for and accept input to the problem solving process from various human users. The user will interface with the knowledge resources and the blackboard to design the joint and then locate or develop an appropriate welding procedure. The WJP configures this information in the form of a Job Description which is in turn passed to the Welding Job Controller (WJC) for the actual execution of the weld.

The Welding Job Controller (WJC) is in charge of coordinating and controlling the various equipment used for the weld, including the welding power supply, the manipulator, the vision system, and other support equipment. This WJC is an intelligent adaptive system. In the WELDEXCELL System being delivered to PSNS the WJC will take data from two sensors, an arc gap controller and a vision system which will be reporting real-time information regarding the three dimensional torch location with respect to the weld seam location and modifying the manipulator path to make corrections from the designed path. At the end of a weld pass, a weld results file will be prepared by the WJC and can, if necessary, be passed back to the WJP for analysis and possible modification to the next pass job

description. The WJC is being made as generic as possible in order to permit the WELDEXCELL System to be compatible with multiple torch manipulators including various robots.

WELDEXCELL Technical Developments

A number of specific technical developments were necessary to implement the WELDEXCELL System WJP described above. The technical issues involved are described briefly in the following paragraphs. Figure 3 is a schematic representation of the WJP showing the individual constituents of the software.

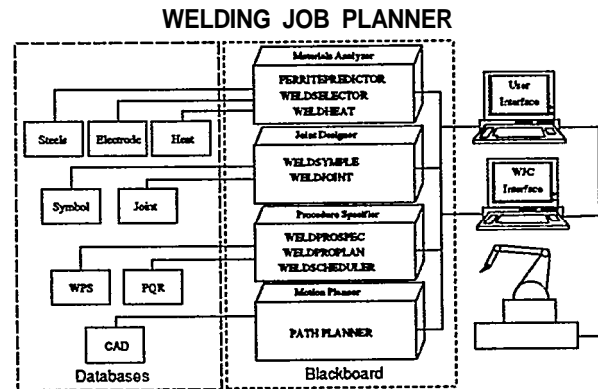


Figure 3

Welding Job Planner Blackboard System

WELDEXCELL consists of a series of expert systems and databases which can engineer and plan a weld, and interact with the user through a blackboard architecture to accomplish each of the required tasks in the weld planning sequence. These tasks include: welding filler metal or electrode choice; joint design and welding procedure selection and development; and robot path plan design and integration with the welding procedure. Finally, the information must be communicated to the fabrication facility in the form of a joint design drawing with a welding symbol and a welding schedule. Each of these tasks is not completely independent and, in the existing manual mode of operation, they are often done in an iterative manner.

The operation of the WELDEXCELL system depends on the interaction and action of several knowledge sources. In this context, we include as knowledge sources, expert systems, data systems (both alpha-numeric as well as graphical and iconic), human users, and artificial neural networks. There are three important features of the WELDEXCELL WJP System which provide this capability. First, the system includes an expert integration environment which allows sharing of information and interaction of all of the knowledge sources. Second, a computer-aided design tool is included to assist in the development of the welding design and drawing.

Finally, a simulation environment, with Computer Aided Design (CAD) interfacing capability, is integrated so that the joint design, welding process and procedure can be tested prior to the welding operation.

Basic blackboard model. The type of distributed problem-solving in multiple knowledge domains (areas of expertise) involved in this multi-disciplinary engineering problem cannot be addressed using a single knowledge source (KS). Rather, multiple knowledge sources and humans cooperate to solve a broad problem. The technique which was applied to this data and knowledge-integration problem was the blackboard architecture. A blackboard system was chosen for the expert integration environment because it possesses capabilities to support problem solving by accounting for diverse types of information, combining various types of data and resolving conflicts, and accommodating different program modules without requiring a complex interface.

A good analogy to a blackboard system, illustrated in figure 4, is that of a group of experts seated before a blackboard, with only one expert allowed to approach the blackboard at a time. A monitor is empowered to call on the experts individually to modify the blackboard's contents. Following each contribution, the monitor evaluates the state of the blackboard's contents and, based on its planning algorithms, considers which expert to call on next. Eventually, the monitor and the experts fill the blackboard with a solution to the problem. If the "experts" described in this scenario are replaced by knowledge sources, a computerized blackboard system results. The monitoring and control functions are performed by what is essentially another expert system with planning algorithms designed to move the expert system toward a problem solution.

HUMAN BLACKBOARD SYSTEM

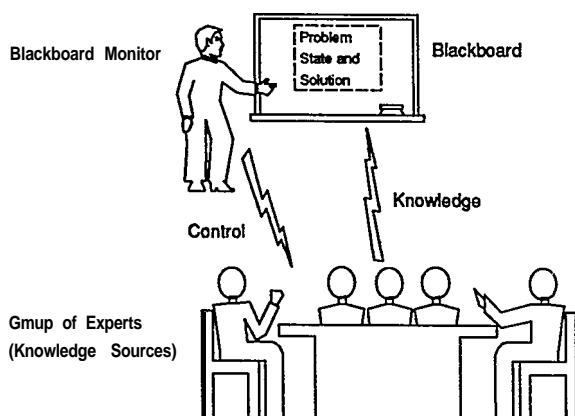


Figure 4

The concept of blackboard architectures was discussed in the literature as early as 1962; however, no applications were built until the late 1970s. The blackboard model was chosen to be used for this expert integration environment because it possesses capabilities to support problem-solving while accounting for diverse types of information, methods for combining various types of data while resolving conflicts, and the ability to accommodate different program modules which allows a completely modular approach to the software (i.e., new knowledge sources can be easily added, or updated, with little integration effort).

The problem solving technique applied to the blackboard model is: dividing the problem into loosely coupled sub-tasks which are then operated on by the specialized knowledge sources for each of those sub-task areas. The advantage of such a system is that much larger quantities and a greater diversity of types of information can be used in a fully integrated manner to solve the problem and develop a weld plan. The human experts supply the external information about the required welding task and then review the final plan. The system also possesses facilities to query a human expert in the event that conflicts outside of the system's domain expertise occur. The time required by a human expert to resolve conflicts is substantially reduced, thus allowing more design and planning to be accomplished with higher overall quality and reliability by the same number of these human experts (i.e., welding engineers). Figure 5 shows a schematic diagram of the operation of the blackboard. The system divides the problem into two different domains: that of the user and that of the knowledge sources. Thus, through the blackboard architecture, the user solves the problem in his/her reference frame while the system simultaneously solves the problem in the knowledge source reference frame. The blackboard, using the specially designed user interface, allows full communication between the two reference frames while the problem is being solved in the most comfortable way by both the user and the other knowledge sources in the system. This is accomplished by treating each of the knowledge sources as a system that can interface to the blackboard in the same way

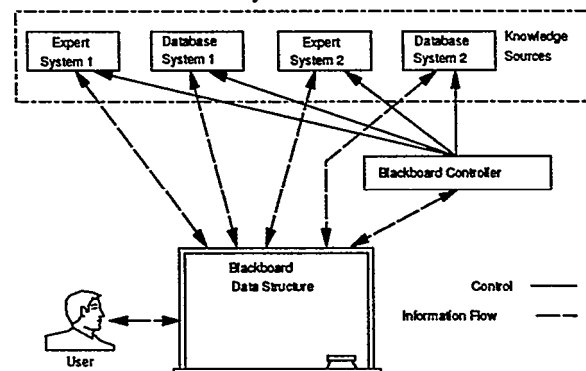


Figure 5

The blackboard's purpose is to provide a framework for the interaction of the multiple independent knowledge sources and to respond opportunistically to the changing contents of the blackboard to achieve a solution. There are seven behavioral goals for the intelligent blackboard control system to accomplish this task. They are as follows.

- ◆ Make explicit control decisions that solve the control problem.
- ◆ Decide what actions to perform by determining what actions are desirable and what actions are feasible.
- ◆ Adopt control heuristics that focus on action attributes which are useful in the current problem-solving situation.
- ◆ Adopt, retain, and discard individual control heuristics in response to dynamic problem-solving situations.
- ◆ Decide how to integrate multiple control heuristics of varying importance.
- ◆ Dynamically plan strategic sequences of actions.
- ◆ Reason about the relative priorities of knowledge domain and control actions.

The blackboard controller. The controller controls the blackboard, monitoring the activities of the knowledge sources, attempting to find a solution to the welding problem. At various levels, ranging from abstract to very detailed, decisions are made, such as which problem to solve next, whether forward or backward chain reasoning is to be used, and which knowledge source to activate. While building a second blackboard to control the problem-solving blackboard is a complex solution, it provides the flexibility to solve both broad planning problems and perform detailed scheduling.

The blackboard control system contains support for meta-level facilities; that is, for the capability of the blackboard to modify its own behavior depending on the solution currently posted on the blackboard. The blackboard is divided into multiple partitions which contain classes. The classes contain objects. The objects, which contain the data used by the knowledge sources to solve a problem, are placed in the blackboard by knowledge sources or by external processes such as human interactions or interaction with the databases.

Another concept for organizing problem-solving with multiple, diverse cooperating sources of knowledge has also been applied to the blackboard. A hypothesize-and-test paradigm is a mechanism which can provide a high degree of cooperation

among the knowledge sources. Thus, the solution finding is an iterative process, which involves two repeated steps:

- 1) Create a hypothesis (an educated guess about some aspect of the problem); and
- 2) Test the plausibility of the hypothesis.

Preweld engineering/planning. The blackboard is presented to the user as an onscreen Welding Procedure Specification (WPS) that is filled in by the knowledge sources as they determine appropriate answers for the necessary WPS data entries. Since information can be changed as more facts are deduced, some data spaces on the interface screen do change in the process. The user interacts with the blackboard by selecting window based menu items using the mouse as described later in the section on the user interface. The display shows initial information (such as material type and joint geometry) and the evolution of the WPS as it is developed, including the joint design, robot path planning, and simulation information. The blackboard controller, which controls the blackboard and monitors the activities of the knowledge sources, attempts to find a solution to the weld design problem. The blackboard controller is written in object oriented C language interfaces directly with the expert systems and controls interactions with the user. The main problems the controller must solve determine a set of goals which are the drivers of the system actions. These goals are:

1. Select Joint design
2. Determine Weld process
3. Select Filler metal
4. Write the Procedure including:
 - (a) Number of passes
 - (b) Voltage,current, travel speed, electrode (filler) feed rate
 - (c) Preheat and postheat requirements
 - (d) Inspection and other requirements
5. Develop welding symbol and other joint details in CAD
6. Download control information to the robot

The specific details of this pre-weld planning and engineering activity are described in the discussion about the User Interface which follows.

USER INTERFACE

The concept of this CAE and planning system which motivated the user interface was to design a system that is primarily driven by the user, not the underlying software. To provide a system that is "transparent" to the user and thereby allows the user to proceed at their own pace and approach with the software operating in the background. Yet, the interface had to be able to allow extremely powerful engineering software to operate and to accomplish all of the routine engineering tasks without the user

having to remember which systems to call at any given time in the engineering process or how to use them.

Since the interface is primarily represented as a Welding Procedure Specification (WPS) with associated graphics entirely on the screen, there is insufficient space available to provide all of the data

to the user at any given time. Instead, each specific section (e.g. joint design, robot simulator, etc.) is "opened up" by clicking with a mouse. The user can then access all of the information in that section while remaining dynamically "connected" to the remainder of the system. A screen print of the highest level interface is shown in figure 6.

HELDEXCELL American Welding Institute

Path Planner **Weld Process** **Power Source** **Welding Procedure Specification**

Base Metal
 Spec. Grade Thickness in
 Spec. Grade Thickness in
Filler Metal
 Spec. Grade Diameter in

Weld Position **Progression**
Shielding Gas **Flow Rate Range** CFH
Purging Gas **Flow Rate Range** CFH
Tungsten Type **Tungsten Size** in
Torch Type **Cup Size** in
Travel Speed in/min **Wire Feed Rate** in/min
Welder Qualification

Part Detail **Electrode Characteristics** **Polarity**

Pass No.	Elec. Size	Amperage	Voltage
1-2	1/16	200	25
3-5	1/16	250	25
6-8	1/16	250	25
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A

Action Panel

Preheat and Interpass Temperature
 F Min. F Max.
Cleanliness **Inspection** **Remark and/or Notes**
Joint Design **Bead Sequence**

Diagram 1: A cross-section of a V-groove joint with dimensions: 4R, 1-1/8", 1/4", 1/8".

Diagram 2: A shaded drawing of a weld bead.

Figure 6

As information is determined by the-expert systems and knowledge and data sources, the onscreen WPS is constantly updated. The display shows initial information (such as material type and joint geometry) and the evolution of the WPS as it is developed, through data searches or "writing from scratch." The user can interact with the blackboard by using the mouse and the keyboard when the system needs the user to provide, or when the user wants to provide, information to the system. Messages are communicated to the user via "pop-up" windows and menus. During path planning and simulation, graphical displays of the simulated robot are provided.

Computer Aided Design and Graphics

A major part of any engineering task is necessarily graphic or picture oriented. Therefore it was important for the system to be able to provide the

user with a very rich environment for graphics and other analogic knowledge. A CAD system was developed for use with this interface that is completely welding specific. It easily communicates with the blackboard by providing drawings of the pieces to be assembled into a fabricated part in 3 full dimensions. Details of the joining of these pieces is included in the CAD representation. A special welding CAD system was developed which is compatible with the ANSI/AWS A9.4-9x standard currently under development. In some cases the rendering of a shaded drawing may be necessary to visualize the welding environment; this is possible using the system. Three separate areas of the interface are provided for CAD based weld engineering: Part Design, Joint Design, and Joint Detail. Features include an expert system to draw the welding symbol and welding specific graphics like standard joint designs, welding bead placement, etc. This CAD system is fully interfaceable to any other

CADKAE system that uses standard data exchange formats (i.e. IGES and DXF). Thus the user can do all or part of the CAD work in another CAD system and download automatically to the WELDEXCELL system, and can modify existing mechanical drawings from another CAD system with welding specific details as necessary.

Part Design. The CAD Part Design sub-system is used to produce a CAD representation of the part to be produced. This sub-system can contain a welding "layer" or overlay segment which describes the weld bead and weld path to be produced. If the weld overlay segment is used, then this system provides the facility to automatically provide the robot simulator with a CAD representation that can be used by the simulator to automatically complete the path plan for the robot and do collision detection. Figure 7 shows this Part Design sub-system window opened. Opening the window is accomplished by clicking a mouse on the Part Design subsystem section of the main interface.

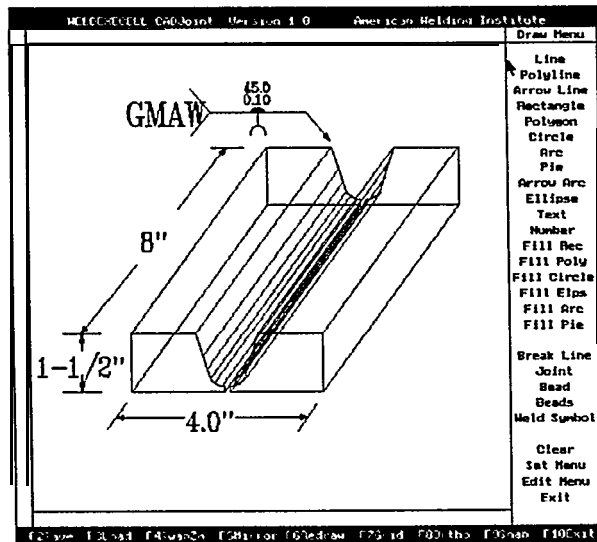


Figure 7

Joint Design. The CAD Joint Design sub-system is used to produce a CAD representation of the joint to be welded. All of the machining details are represented in this sub-system. This CAD drawing can be sent electronically to the machining facility for production of the parts and, if the CAD system being used by the machining facility has the capability, the machining of the part can be done automatically. A Computer Numerical Control (CNC) code can be developed by the appropriate CAD system and then downloaded to a CNC machining center for automated metal removal. Figure 8 shows the Joint Design sub-system window opened-up and the joint design prepared with this sub-system.

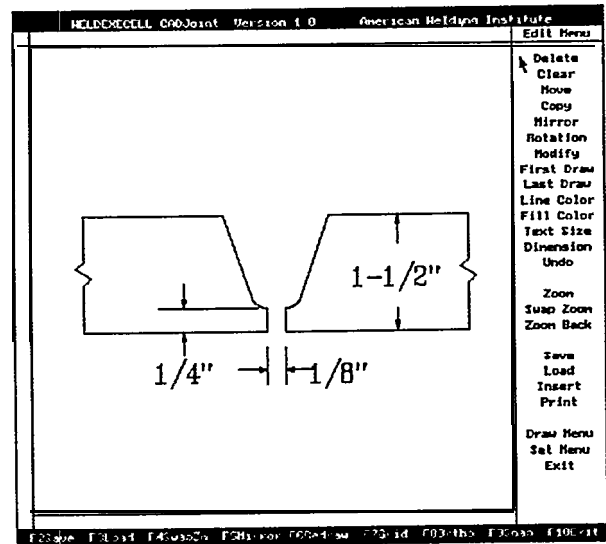


Figure 8

Joint Detail. The CAD Joint Detail sub-system provides the engineer using WELDEXCELL to prepare a joint detail in the CAD system that includes the weld bead design, placement, and sequencing. This sub-system includes a facility to draw the weld bead according to the ANSI/AWS A9.4-9x standard for CAD Layers. The user can place all of the weld beads for a multi-pass weld and automatically sequence the beads for multi-pass welding. Figures 9a and 9b show the Joint Design window open and the detailing of the weld beads being made using this sub-system,

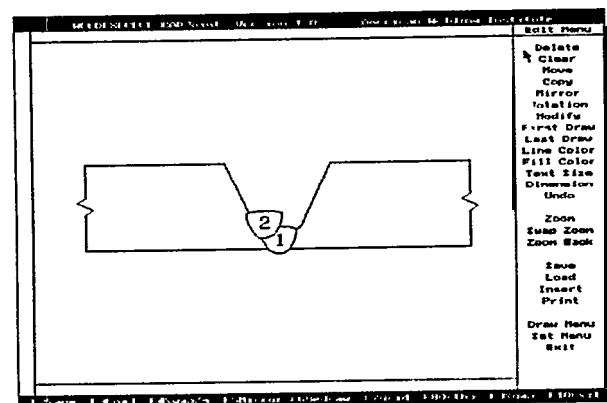


Figure 9a

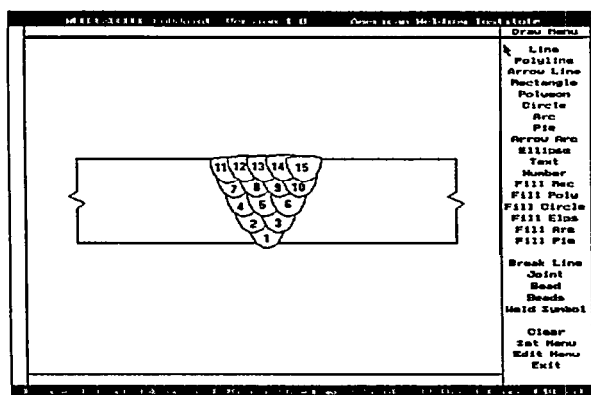


Figure 9b

Robot Simulator System and Path Planner

The Robot Simulator System allows the user to simulate the robot movement relative to the workcell and the parts to be welded by downloading the parts from the WELDEXCELL CAD system (or other CAD system) into the simulator. The Path Planner automatically plans the robot movements thereby eliminating the necessity to do the path planning with the actual robot. The WELDEXCELL system produces robot path and motion control information in a format which is fully compatible with the supported robot systems. The simulation graphics assist in planned path verification and collision avoidance. The system is capable of providing an environment which allows the user to prepare for a robotic welding application without ever using the robot system. WELDEXCELL has overcome the most significant problem with regard to the use of robot systems for the "ordinary" (few of a kind) welding applications, thought to only be capable of being done economically with semi-automated or manual welding.

Once the weld is designed and the weld path is placed into the weld layer in the CAD system (using either the WELDEXCELL interface or another CAD system), then robot path planning is automatic. The path planner includes a full kinematic model of the robot system as well as an interpreter/writer of program code in the language of the robot controller. If the fixturing and other "collision objects" are included (e.g. downloaded from the CAD based fixture design) in the part design, then the path planner will also do a collision detection for the workcell. This provides the user with a nearly complete automatic system for robotic weld planning, programming, and development. The only additional algorithm needed in follow-on work is to develop a collision avoidance system that can re-plan the robot path whenever a collision is detected. Such a system may be included in later releases of WELDEXCELL. A typical robotic weld path plan and weld simulation, including collision detection, is performed by the Robot Simulator System, as shown in figure 10.

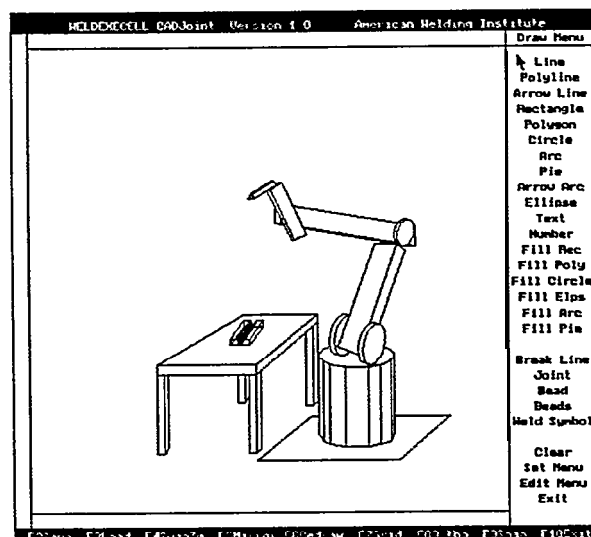


Figure 10

Welding Schedule Development

Finally, the WELDSCHED expert system ties the robot path plan together with the welding procedure into a full weld schedule that can be automatically downloaded by electronic network to the welding workcell. In addition, with the appropriate software in the workcell, robot path modifications or procedure/process changes can be incorporated into the weld schedule and uploaded back to the database of the Welding Job Planner.

NEURAL NETWORK BASED WELD

The planning and engineering of a weld requires that the welding engineer have available the necessary information to select appropriate welding parameter values such as voltage, current, travel speed, and wire feed rate. However, arc welding processes today are far more complex than can be modelled using mathematical relationships. Thus, the selection of optimum parameter values is a "seat-of-the-pants" type operation which includes much testing and "educated guessing" to develop a new welding procedure.

WELDEXCELL includes an Artificial Neural System (ANS) based weld modelling package that allows the welding engineer to "try" various combinations of welding parameter values working at his or her desk before generating a welding schedule. Thus the welding schedule that is electronically transmitted to the workcell is nearly optimum and need little, if any, changes on the shop floor. This eliminates a large amount of engineering time and effort in comparison the "typical" methods used to develop welding schedules.

Artificial Neural systems

Artificial Neural Systems are an attempt to develop computer systems that emulate the neural reasoning behavior of biological neural systems (e.g. the human brain). As such they are loosely based on biological neural networks. The ANS consists of a series of nodes (neurons) and weighted connections (axons) that, when presented with a specific input pattern, can associate specific output patterns. It is essentially a highly complex, non-linear, mathematical relationship or transform. However, it is not necessary for the developer of such a system to understand the basic underlying principles of a process in order to develop a highly accurate ANS based model of the process. Thus, in this way it is quite different from other mathematical modelling approaches.

The problem of ANS's is to decide how many nodes and connections to have to model a specific problem, to decide how to configure them, and to decide the specific values of the connection weights and the transfer functions that exist within the network. Figure 11 shows a schematic diagram of a neural network and Figure 12 is a simple representation of the weights, transfer functions, and the mechanisms of network operation. As can be seen, there is no direct known correspondence between the network parameters and operation and the problem to be modelled by the network. As a consequence, there is currently a dearth of mechanisms which can be used to assign the weights and transfer functions in the network so that it can solve a problem.

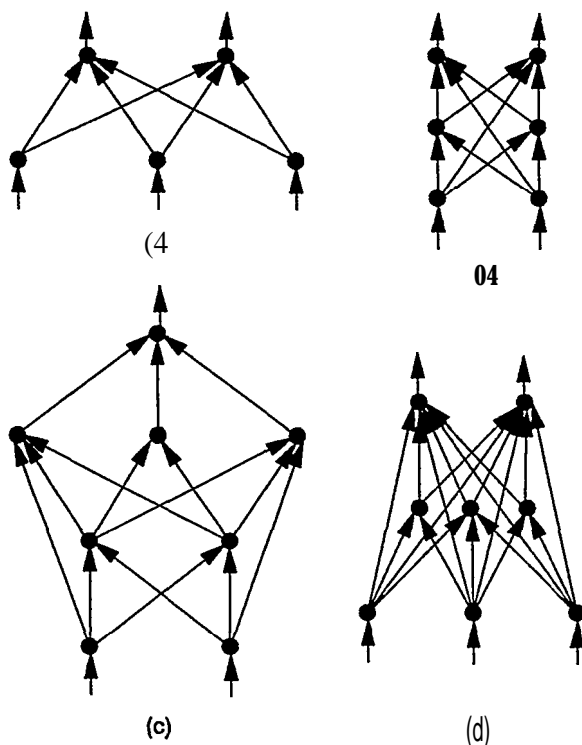


Figure 11

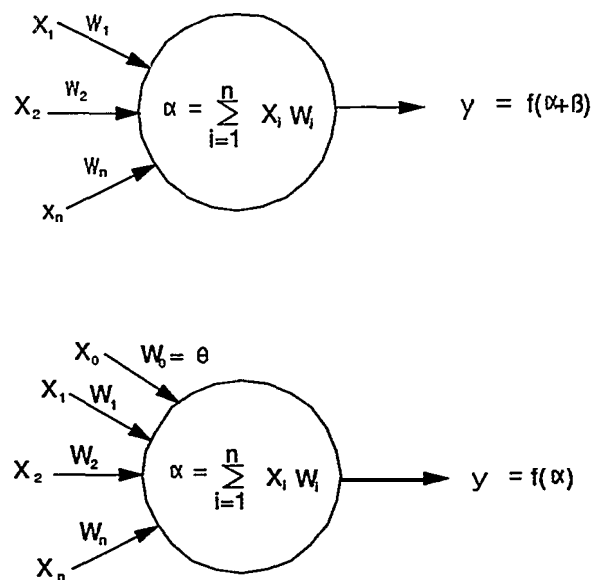


Figure 12

One of the most successful approaches that has yielded good results in developing networks is known as the "back propagation" method. In this method, the network is "trained" as a model, rather than being programmed. The back propagation method assumes that the search in weight space for an optimum, or near optimum, network configuration can be accomplished as an iterative search using the error gradient in L_2 space. That is, a series of moves are accomplished on the multidimensional error surface using the maximum mean squared error gradient as the move direction at each iteration. The error in the network is defined as the difference between the desired output representation and the actual output given the current weight matrix values. By calculating the maximum gradient of the mean squared error for any given training example (set of input and corresponding output patterns), the weights are adjusted so that the net moves along that gradient direction in each presentation of the training example to the network. Using this procedure, the network slowly "learns" to associate all of the training example input patterns with the correct corresponding output patterns.

This "basic" back propagation learning process has several significant drawbacks. First, the configuration (i.e. number and relative location of hidden representation units or nodes) cannot be pre-determined and needs to be pre-assigned by using an "educated guess." Since the node configuration can significantly affect the operation of the network, this will at best lead to a long series of re-trials and at worse to no useful network at all. Second, this process is very slow and the rate of learning (convergence to near zero error) is set arbitrarily --traditionally at a value between zero and one. No known method for predetermining the learning rate (gain term) will consistently choose an optimum value and the optimum value is signifi-

cantly influenced by the specific problem being presented to the network. Third, it has been shown that it generally requires a larger network to "learn" a problem than is required to solve the problem. There is no known method of reducing the size of the network optimally after training to optimize the net performance. Finally, learning instabilities exist in nearly every problem which will cause the network to stop learning (converging). One of these instability types, known as a local minimum, has been studied and reported in the literature, but it is often not possible to overcome this problem when using the traditional back propagation method.

The Delta Activity Network

The developers along with several Ph.D. and Masters student projects, developed a new method for training neural networks that has been shown to overcome all of the known problems with the back propagation method, while maintaining the inherent stability and known network development capabilities of the pack propagation method. This network was developed through the use of a thermodynamic model of the network operation which included both the delta energy but also the activity or kinetics of network. This methodology has led to an algorithm that is being patented. This technique, known as the Delta-Activity™ Network (D-A Net), has been used on several applications ranging from high speed signal processing to vision systems and includes the weld model system currently being used in the WELDEXCELL System.

The D-A Net has achieved learning rates as high as 1000 times that of the back propagation method while also preventing the network-from falling into learning instabilities. Research conducted on the D-A Net has confirmed the existence of at least three types of learning instabilities (local minimum being one of them) and the D-A Net algorithm can avoid all three of them. In addition, the D-A Net configures itself dynamically during the learning process and so it can produce a near optimum network size for operation, often much smaller than the network needed to "learn" the problem. By the combination of dynamic self configuration and learning instability avoidance, an operating network is virtually guaranteed for all problems.

Weld Model Neural Network

A network was trained to model a flux cored arc welding (FCAW) process. The network model has inputs of voltage, current, and travel speed. The outputs of the network, for a fillet weld on an L joint are: arc stability, penetration, vertical and horizontal leg lengths, amount of spatter, bead appearance, bead undercut, and ease of slag removal. Figure 13 is a schematic representation of a weld bead depicting the morphological features which are network outputs. Twenty-eight welds were produced and examined to obtain the training set for the D-A Net.

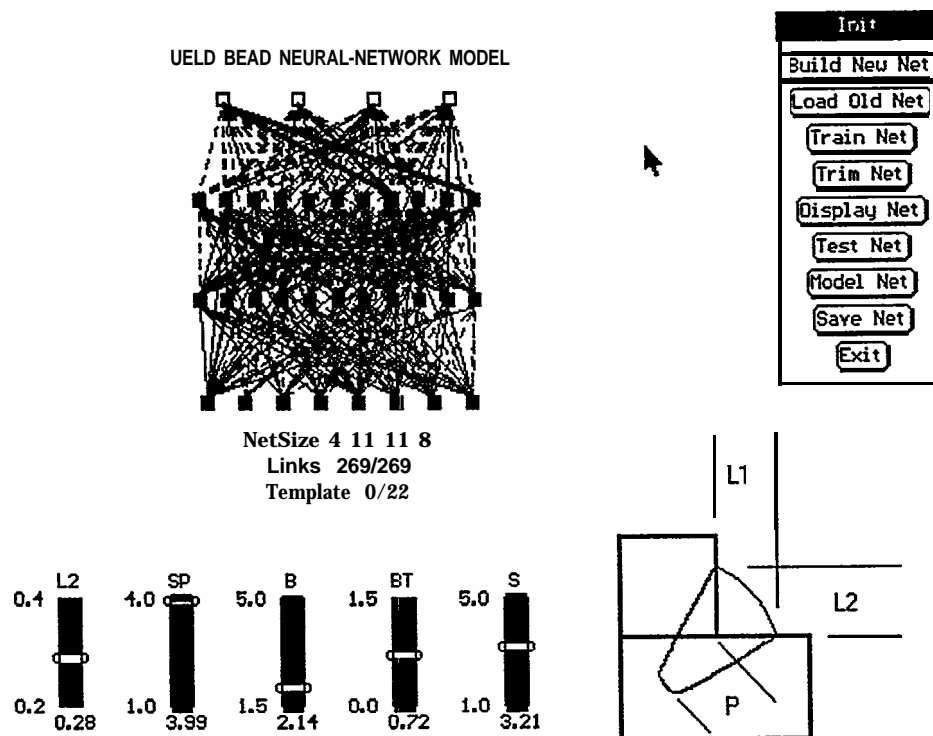


Figure 14 shows the user interface to the network running on a DOS based computer using a 386SX processor. On the screen are several mouse sensitive slide bars that can be set by the user or observed by the user. The first row of slide bars are mouse sensitive and represent voltage (V), current (I), and travel speed (T). These can be moved to new values by using the mouse to "slide" the bar. The resultant weld is shown in cross section in the graphic window to the right of these slide bars. As the user moves these slide bars, the weld bead graphic moves in real time. In addition, the seven slide bars in the second row show the values of the output of the network. This represents a very powerful planning tool for the welding engineering workstation. Also shown on the screen is a tool for the welding engineer to use

to design a control scheme (which could be used to design an intelligent welding process controller). The final row of slide bars has a set of small boxes next to each slide bar. By using the mouse the user can choose the relative importance of each of the output parameters of the network, the top box indicating greatest importance and the bottom box representing no importance. Once the importance factors are set, the user can use the mouse to set values of these output parameters. Then an integrated inverse network finds the values of voltage, current, and travel speed that will result in the chosen output parameter values, weighted to the importance values. Figures 15a through 15f shows a sequence of workstation screens indicating a typical session with the D-A Network weld model.

WELD BEAD NEURAL NETWORK MODEL

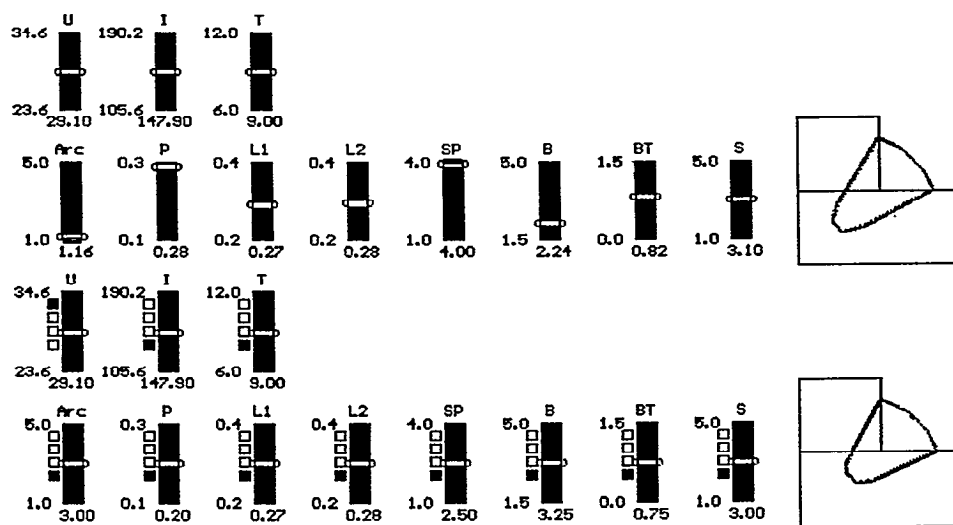


Figure 14

WELD BEAD NEURAL-NETWORK MODEL

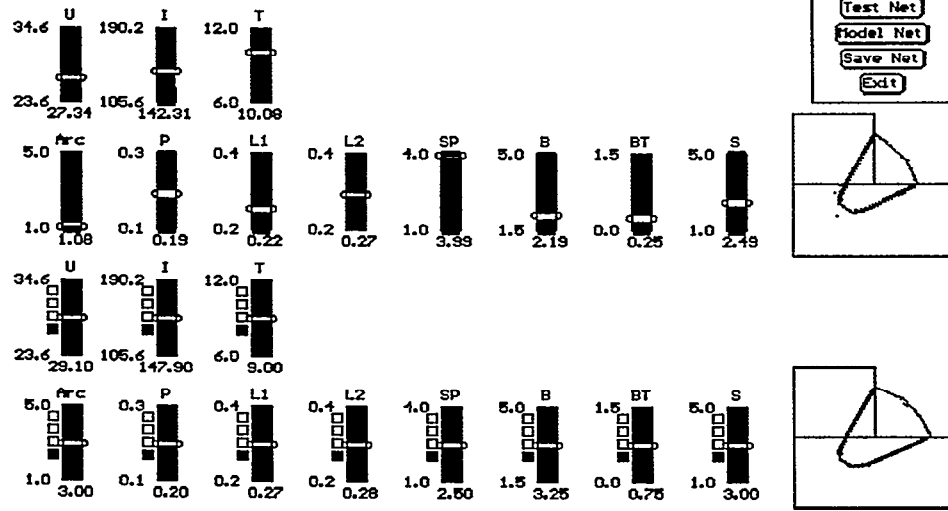


Figure 15a

WELD BEAD NEURAL-NETWORK MODEL

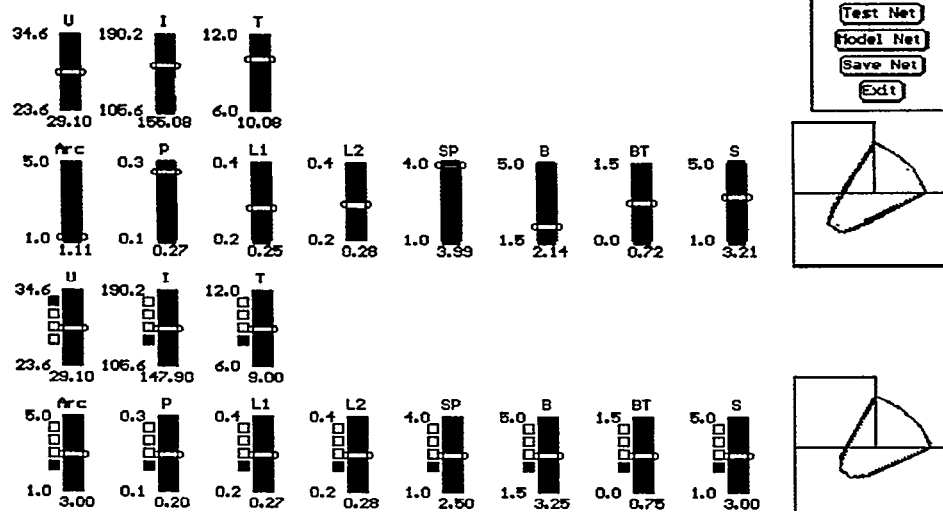


Figure 15b

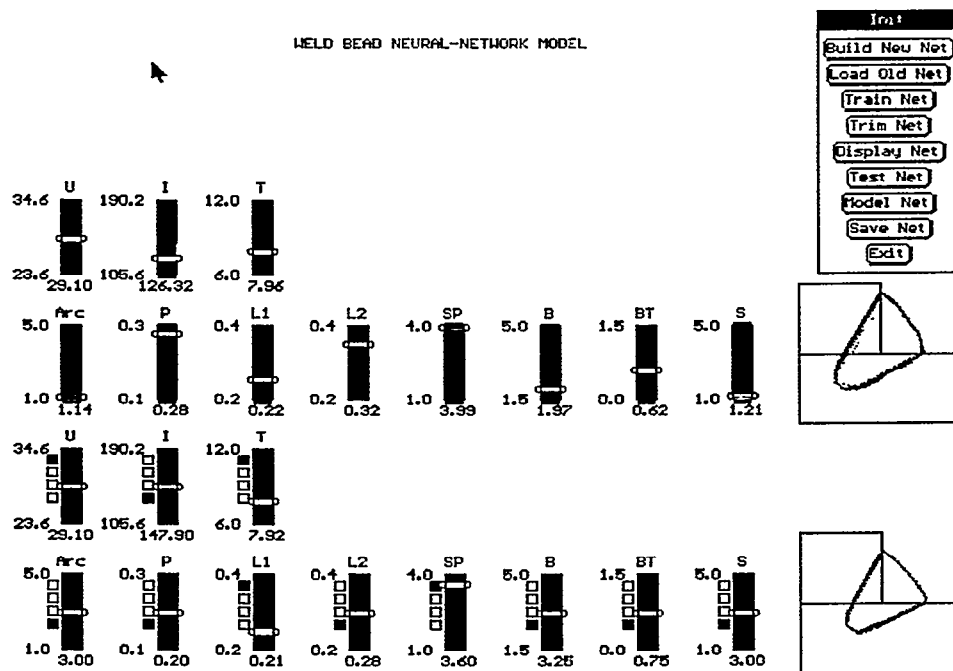


Figure 15c

CONCLUSION

It is clear that an advanced engineering workstation can provide a welding engineer with a significant productivity tool. The application of advanced computer tools to welding engineering allows a virtually paperless engineering environment in which the engineer has, through these tools, all of the necessary reference data and information to completely plan and engineer a weld. The work that previously would take several days can now be accomplished in a matter of minutes. In addition, the engineer has tools available such as the D-A Net weld model that were never feasible before; consequently, much better engineering will be possible using the WELDEXCELL System. Finally, the system offers the capability to electronically download welding schedules, both for manual as well as automated welding, to the shop floor or robotic workcell. This eliminates the need for large

amounts of paper and much faster throughput and communication between the shop floor and the engineer. The result is a significant increase in productivity and quality of welded components in the shipyard.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the United States Navy Office of Manufacturing Technology, without which this project would not have been possible. Puget Sound Naval Shipyard has provided technical assistance, beta testing of the software, and will be the site of installation of the first WELDEXCELL System. In addition, the United States Naval Sea Systems Command and their contractor for project management, CASDE Corporation, have contributed to the overall success of the program.



Portable Arc Welding Robots - A Practical Shipbuilding Tool?

IIB-3

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ABSTRACT

An overview of the application of portable welding robots in shipbuilding is given, with particular reference to a pilot project undertaken at a British shipyard. A general basis for cost justification is outlined, and applications and limitations of the robot system discussed. Particular attention is drawn to the requirements imposed on other shipyard systems when using robots.

INTRODUCTION

Developments in Japan

In the mid 80's the Japanese shipbuilding industry, supported by funding from their Ministry of Transport (MOTO) invested heavily in a 5 year R&D program to develop a range of devices to automate arc welding, painting, assembly and other shipbuilding processes.

The objective was to make shipbuilding both more attractive to the Japanese workforce, since recruitment was becoming increasingly difficult due to poor public image and inferior salary structure of the industry, and to create manpower savings within what was (and remains) a labor intensive industry. The intent was to improve productivity and thereby address the considerable price differential existing with respect to the Korean yards on newbuilding contracts.

A productivity improvement target of between 60 and 100% over a ten year period was felt necessary to redress the situation. The major yards themselves believed automation on a large scale offered the only realistic means of attaining this target.

Assessment Of The Need For Robotics

The most commonly quoted reasons for introduction of robots are:

- improved quality;
- low labor costs;
- greater volume of output; and
- improved working conditions.

In actual fact, these are incidental benefits as the only real reason for introducing robotics or any other item of capital equipment is to make more money. That is, to increase profit, give an acceptable return on the investment and to maintain an adequate cash flow (1).

However, before assuming that robotics or automation is the key to making more money, a detailed business review should be undertaken to determine where the priorities lie.

Typically, in shipbuilding, it is found that the most profitable investments can be made by concentrating on systems rather than hardware, for example:

Design - to reduce work content;

Planning - to organize the work in the most cost effective manner and to ensure that the right material and information are in the right place at the right time; and

Quality - to eliminate defects at every stage.

However, it may be felt that such systems either have already been developed to the point at which further benefits will be difficult or expensive to make (as in some Japanese yards); or will be in the foreseeable future. In such a case, introduction of robotics may give a higher return than other investments in production hardware or software.

Also during the mid 80's British Shipbuilders were themselves striving to significantly improve the production performance of their subsidiary yards by various methods including low cost automation (2). A high level executive study tour of Japanese shipyards was therefore undertaken to view the Japanese shipbuilding methods and equipment. A range of robotic devices, components of the MOT0 funded initiative, were viewed during the visit and their potential quickly realized. The Japanese yards were already substantially more productive than their UK counterparts and it was considered that widescale adoption of automation could well place them completely out of reach. British Shipbuilders initiated a program to consider the benefits and implications of introducing such automation within the UK industry. Recognizing the effort the Japanese were devoting towards the design and implementation of robotic devices, it was considered prudent to similarly consider the production possibilities of robots.

ROBOT SELECTION

A very large number of different arc welding robots were available during the investigation period.

The majority of these were of the fixed location revolute type developed for general engineering duties. These offered only a limited working envelope and demanded that the workpiece be presented to the robot for welding. An extensive program of trials with such a robot type had already been conducted by British Shipbuilders (3). Whilst of benefit in creating an understanding of robotic arc welding, together with the associated supporting disciplines applied within the shipbuilding environment, such machine types are not well suited to the mainstream of shipbuilding construction. Robots within this general category were not considered further.

Additionally, any robot not capable of seam tracking, or rapid recognition of the spatial relationship between itself, the workpiece and the weld start point was similarly discounted as being unlikely to address the production realities of shipbuilding. Any robot welding systems without such software capability were excluded.

It must be realized that the total world market for arc welding robots in ship building is small in relation to the order-of costs likely to be incurred in the development of systems with the necessary mix of hardware and software complexity. There exists therefore insufficient

commercial synergy between the manufacturers of such robot systems and the shipyard end user to develop the systems in the first instance without recourse to "independent" funding.

Two distinctly different robot "types" remained after the initial filtering exercise was completed. It is not surprising in view of the above that these machine types had each been developed specifically for welding operations within shipbuilding. These are:

- (a) Large multi (>6) axis machines which can automatically access all points to be welded on the workpiece. Movement from one job to another on the workpiece is carried out by at least two more axes on a travelling support, either a gantry or base, which is not controlled during welding. These axes are commonly used for coarse placement of the robot. Sensors are then used to detect the actual position of the job.

Examples of this type are the Hitachi Unit Welding Robot as deployed at the Ariaki shipyard in Japan, and the Rosenlaw, Wartsila, Kemppi joint development installed at Helsinki.

The working envelope is dictated by the length and spacing of the rails or beam outreach. Due to the limitations of working envelope size and location, production planning and material control need to be more disciplined. Whilst this in itself is obviously beneficial, failure to achieve such discipline can present a major obstacle to the successful use of robots in a poorly organized shipyard. The capital investment required for this sort of system is substantial, and return on this investment is dependent on a high throughput of (usually) major assemblies (i.e. a healthy and reliable flow of orders) and application to a bottleneck activity.

Such robot systems demand a high degree of uniformity in ship - internal design to ensure machines can gain effective access and reduce the probability of collision between the robot and ship structure. Also demanded is a high degree of accuracy of constituent piece part location within the large assemblies due to potential interference between the robot

arm and the structure. This degree of fit up was considered beyond the capability of British Shipbuilders' yards at this time. By default of their size and complexity, such systems can only operate at fixed workstations within the unit/block assembly areas. The gantry type is suitable only for 2 1/2 D assemblies, such as primary and secondary stiffened panels, demanding completely unhindered top access. The Hitachi column and boom approach enables larger 3D workpieces be processed but nevertheless still requires largely unhampered side access for successful deployment.

Robot welding systems such as these demand that off line programming techniques be employed, since it is patently unrealistic to attempt a teach-program approach.

- (b) Very small machines capable of being moved easily to a point of application as required (Figure 1).

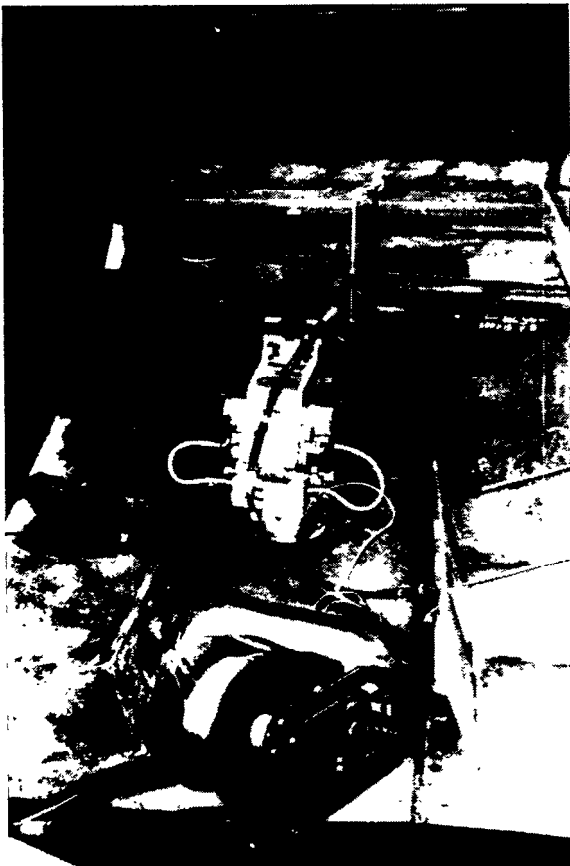


Figure 1. Hitachi M5030Z

The working envelope of such a robot is fairly small, but the robot is repositionable over an area dictated by the length of the various cables between it and the controller and wire feed unit. This working area can be further extended by mounting all the associated hardware (power source, controller, wire feed unit, etc. on, for example, a travelling gantry which can also serve as a support for handling aids. Due to the much more flexible working envelope of the portable robot system, it can cope with a less rigid organisation of material, and is therefore better suited to an initial robot installation where organization of work is less than ideal. First cost is a fraction (typically 1/20th to 1/30th) of the cost of the larger system, and as a result of the much greater flexibility of this configuration, return on investment is not as dependent on a particular type of assembly.

A possible hybrid intermediate between the types of systems is the use of a large "pick and place" robot to relocate a number of portable robots within a more rigid workstation (4).

The potential to use such portable robots both within the unit and block assembly stage and during ship construction on the berth or in the dock was considered significant.

Robot Choice

If block assembly and erection could be reduced from major events (as they were at that time), to routine operations, then a very significant effect upon the overall build cycle times and the effectiveness of capital plant and equipment deployed would be realized (5).

It is important to remember that the ultimate productivity of an arc welding robot is process limited. The robot is merely a sophisticated tool to manipulate a basically standard wire feed torch. The physics of the weld pool itself determine the maximum weld deposition rate, particularly during positional work to which the robot is best suited. Long runs of downhand or horizontal-vertical welds are almost certainly more cost effectively addressed by less sophisticated weld mechanization or automation.

Nevertheless, a robot arc welding system is able to handle higher currents for longer periods than would be possible by a manual welder using a similar process and robots can generate improvements in welding time as a consequence.

The decision was reached to further investigate robots of the portable **type**. Only three machines of this type were known to **exist**:

- Hitachi Zosen WRL 50;
- Yaskawa Motoman V5ZA, and
- Hitachi M5030.

At the time only the Hitachi M5030 was **available**, through **agents**, within the **UK**. This robot type was therefore to be considered for primary introduction within British Shipbuilders, together with its associated programmable welding power supply and wire feed **units**.

Whilst **portable**, this machine is not readily handled manually and it was recognized that bespoke handling aids would need developing to effect rapid and safe transfer between successive work **locations**. Such aids may well need to be structure specific in certain circumstances.

Cost Benefit Analysis

The primary application of automation should be at the hull construction **stage**, as in almost all cases, this will be a **bottleneck**. It can be argued that as the main resource applied is **manpower**, then use of robots in fabrication would release manpower for use elsewhere on the berth or dock and have a direct effect on cycle **times**. There are limitations to this **argument**:

- Too great a manning density will lead to reduced **productivity**;
- Excessive manning levels can result in out-of-sequence work and structural **distortion**;
- In the **typically** restricted spaces of ship **construction**, there is a physical and safety limit to the number of welders who can be **deployed**; and
- Increasing productivity locally in fabrication may unbalance the production system and lead to an increase of work in **progress**.

Although it was intended eventually to introduce robot arc welding throughout unit block assembly areas and the ship construction stage on the berth or in the **dock**, initial assessment of the potential benefits of arc welding robots was concerned only

with the unit assembly stage of ship **production**. It was considered that the more controlled environment and better access possible within the steel shops would be conducive to a more rapid production development **period**. Subsequent introduction to production would be both sooner and more readily managed than elsewhere in the **yard**.

A 22,600 dwt general cargo vessel under series construction in one yard was analyzed to identify those areas which might benefit from the application of the Hitachi M5030 arc welding **robot**.

Selection of the appropriate application took into account the factors that **follow**:

-Repeatability of structure.

-Size of each job (usually defined by all activities carried out by the robot between **relocations**). The repeated elements of structure should be small enough to be welded without relocating the **robot**.

-Access to components. An acceptable torch angle must be maintained along each **joint**.

-Weld positions. The weld positions determine whether another form of automatic or mechanized welding is used.

-Weld length per job. The greater the weld length per job the lesser is the effect of set-up times on the robot utilization. As the robots are designed to operate between **frames**, there is an optimum frame size/spacing range within which set-up times are least significant (**Figure 2**).

-Access to the workpiece. Vertical access is obviously easier than maneuvering the robot horizontally through **manholes**.

Within the ship type **analysed**, the selection criteria were best met by the transverse/deck/longitudinal connections, some 3,300 in total being required per **ship**.

An additional benefit of this application was the knowledge that the **robot(s)** could be initially deployed within a dedicated work area located towards the end of the panel production line.

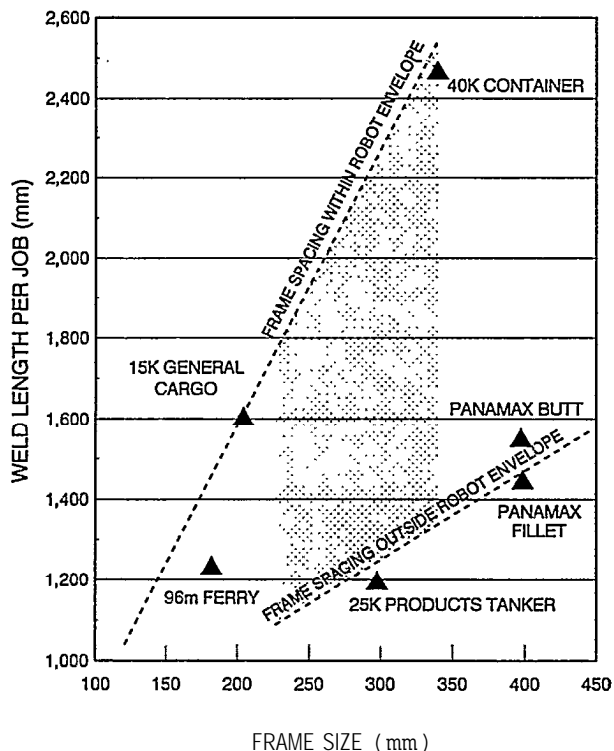


Figure 2. Effect Of Ship Size On Weld Length Per Job

Robotic Welding Times

Setting up times for the robot were obtained from the robot manufacturer, and arcing times were derived from established weld procedure parameters.

Two different deployment methods were considered as described below.

One Man Operating One Robot. In this situation the operator is effectively reduced to a spectator role whilst the welding activity is being performed by the robot and should therefore always be available to immediately re-set the robot at the next work location. A high robot utilization is therefore possible but at the expense of inefficient use of labor.

One Man Operating More Than One Robot. When one man operates more than one robot, there are two possible operational patterns, as follows:

-The total weld completion time of any one robot is shorter than its associated relocation and set-up time. In this situation there exists idle time when one (or more) robot has completed its full cycle but must wait upon the operator completing the set-up of another robot. The time demands upon the operator are

continuous if maximum arc-on time is to be attained from all robots. System performance is thereby restricted by the sustainable labor effectiveness of the operator, an undesirable condition.

-The total weld cycle time of any one robot is greater than its associated relocation and set-up time. The relationship between the arc-on time and set up time will determine the number of robots it is viable to employ under the control of one operator. The maximum possible utilization of each robot can be expected from this scenario.

A cost benefit analysis performed to determine the order of savings which might be expected from the deployment of the robots on the transverse / longitudinal connections indicated a saving in excess of 2,600 manhours per ship was possible. At a production level of some 2.7 ships per year of the series vessel considered, an annual labor saving of over 7,000 steel manhours per year was available. This is equivalent to an internal rate of return on the capital investment of more than 50% over the five year period considered, assuming these 7,000 hours can be effectively utilized during hull construction.

The decision to purchase was given mainly on the basis of this analysis but tempered with a strong need to know just what could and could not be reasonably expected of robotics for arc welding within shipbuilding.

Further investigations were also made to determine the suitability of the M5030 robots to the structure of 40,000t dwt container vessels commencing production at another British Shipbuilders' yard. Figure 3 shows the times required to weld one watertight bulkhead to the bottom shell structure, using:

- conventional semi-automatic equipment;
- one robot worked by one operator; and
- two robots worked by one operator.

It can be seen that cycle times are significantly reduced even when using one robot per operator. This is due mainly to the effects of welder concentration and discomfort which are exacerbated by the long runs required on this structure.

Following this, calculations to determine productivity of the butt welding of longitudinals were undertaken. There is less similarity between different ship types at the hull construction stage than there is at the interim product stages. A

Panamax tanker was selected as providing the easiest structure to which portable welding robots could be applied and therefore the savings indicated would be the best which could be hoped for. Analysis of a typical British Shipbuilders' shipyard with two berths indicated a saving of over 4.5% in the total steelwork hours and a keel lay to launch duration reduction of at least 3 weeks, thereby offering the potential of increasing throughput by over 11%.

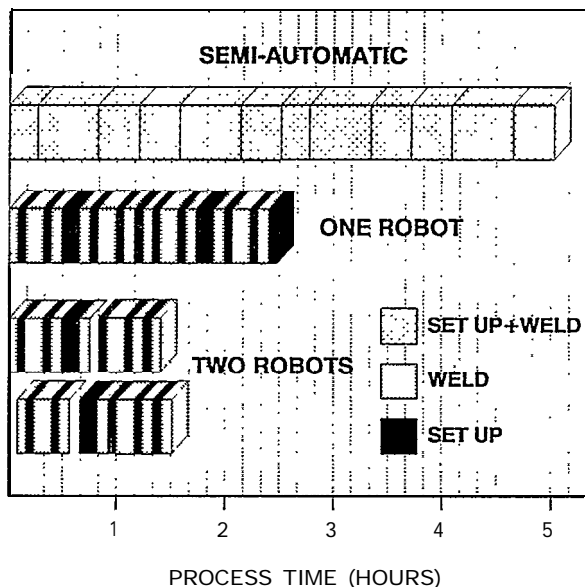


Figure 3. Comparison of Process Times For One Watertight Bulkhead

Development Plans

A training, development and work preparation area was set up in a convenient location adjacent to the workstations for sub-unit and unit assembly. The robot power packs, controllers and other hardware were located in a small enclosure upon the existing services gantry some 3m (10 feet) above the shop floor. This gave a good view of the production area (it was found that it was desirable to be able to see each robot from its controller), and maintained the cables above the floor, thereby preventing damage. This initial installation permitted the machines to be used both in production and in the development area for training and programming.

It was decided that a full scale mock-up should be used for programming (Figures 4 and 5). This allowed each job to be run with the arc off to ensure that the job structure was correct, and that the touch sensing routines, including the handling of

the various shift registers, were error-free. Programming 'on the job' was not considered as it is a time consuming activity which would interfere with production.



Figure 4. Adjustable Mock-Up For Programming



Figure 5. verification Of Programmed Torch Positions and Welding Parameters

A delay in delivery of the robots had lost the original target ship to the program, so trials commenced instead upon the structure of a series of 93m Ro-Ro ferries commencing production.

The vessel midship section, general arrangement and steelwork process analysis was examined with the previously described criteria in mind in order to select an appropriate application. The initial application chosen for the robots at British Shipbuilders was the welding of transverses and transverse bulkheads to longitudinal bulkheads in the sub-unit assembly of wing tanks (Figure 6-1). This application had a further advantage in that only 24m of such joint length was required per day according to the production program. Therefore as each machine is capable of about 10m per hour on such structure, there was ample time for programming of subsequent applications. Whilst the long term aim of the project remained to improve productivity by reducing the ship construction cycle time it was recognized that this application is demanding in terms of weld procedures, accuracy of components, quality of edge preparations and access. A series of increasingly demanding applications was deemed to present the most structured approach to permit designers, management, programmers and robot operators to gain experience prior to final installation of the machines in the building dock. The subsequent applications (Figure 6) selected were as follows:

- Double bottom sub-unit assembly, stage 1 (i.e. welding of transverses to tank top (Figure 6-2)). Access is vertical, and jobs are of a similar nature to the initial application.

- Thruster room center section sub-unit assembly (Figure 6-3). This involves the welding of tightly spaced, deep longitudinal and transverse structure to each other, and to the bottom shell. The thruster room units were long lead units, and this was partially due to the unpleasant work involved in the welding in the confined spaces. Access was vertical but would require operation of the robot in an inverted position.

- Double bottom sub-unit assembly, stage 2 (i.e. welding of transverses to the bottom shell (Figure 6-4)). Job and program structure would be relatively simple and similar to the first two applications, but access would be horizontal, and require the design and manufacture of a different handling aid.

- Unit butts between longitudinal stiffeners after erection (Figure 6-5). Access problems should be resolved by previous applications and designs of handling aids. However, it was anticipated that the midship section of the ferries would not present an ideal structure, due to the

limited joint length per job and the number of decks and tanks. There is a limit on the suitability of portable robots to weld in confined spaces, such as double skin structure, due to the fact that the machines require an operator, who is exposed to fume just as a welder would be. This effectively limits the number of robots and hence the productivity of the application. However, at the time of the project instigation at British Shipbuilders, the shipyard involved had been constructing general cargo ships and large barges for which access and spatial restrictions were less demanding.

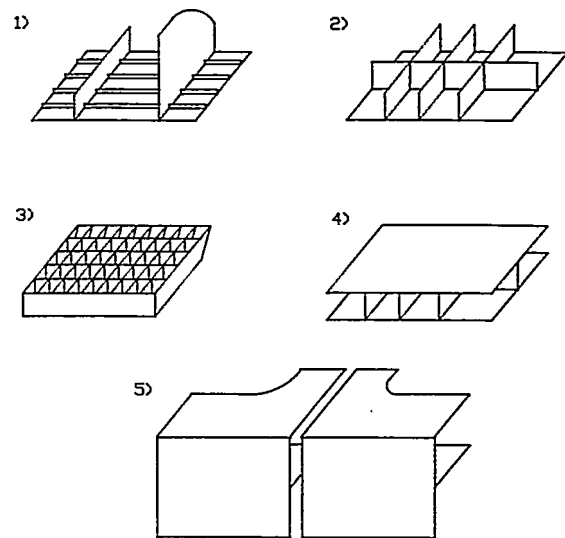


Figure 6. Initial Assembly Types For Robotic Welding

The Hitachi M5030 Portable Robot

The Hitachi M5030 range comprises two models, the M5030T (equipped with a traversing base); and the M5030Z (equipped with a rotating base). The M5030Z model was chosen by British Shipbuilders as this was felt to be more useful for welding typical ship structure (Figure 7).

The body is of the revolute (jointed arm) configuration, having five simultaneously controlled axes. An optional auxiliary twist axis on the wrist was selected in order to give maximum flexibility. The general design of the wrist differs from conventional welding robots in that the torch is mounted above the joint, thereby allowing greater access into tight spaces, and reducing interference problems with the workpiece.

The controller for the M5030 range is based upon a 16-bit

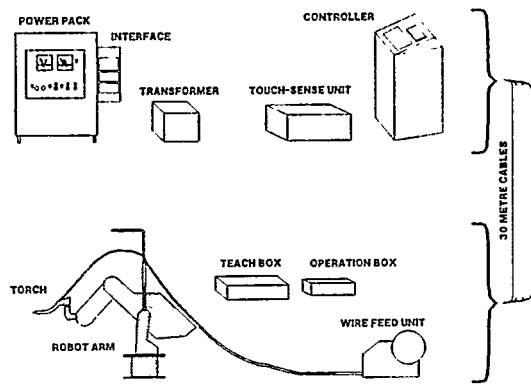


Figure 7. Hitachi M5030Z System Components

microprocessor, giving a maximum of 256 programs, and 100 jobs. A program or job may contain 2,000 steps. Path control is by continuous path using either articulate, linear or circular interpolation in any plane. In addition to the usual controller modes (e.g. program teach, playback), a diagnostic mode, and a monitor mode (to display production control information) are supplied. A tape streamer is used to backup job and program data, and to transfer it between controllers. The weld parameter database can store 100 combinations of current, voltage and speed. All these parameters and timers may be changed on-line via the teach-box. The teach-box, along with all these usual servo controls and condition buttons, has manual control of wire feed, and arc-on (for tacking). An operation box with remote over-ride of certain controller modes and functions (sufficient to operate the robots without reference to the controller) is also supplied. The robot body, operation box and teach-box are connected to the controller by thirty meter cables, enabling the robots to be used over a substantial area. The remaining hardware consists of a touch sensing unit (also used for seam tracking); the welding power supply and robot interface; and a transformer.

PROJECT FINDINGS

Robot Arm Design

Although the project specification for the design of the portable robots built by Hitachi, Hitachi Zosen and Yaskawa called for the machines to be light enough to be carried by two men, and to enable them to pass through a standard manhole, it was discovered that the robot arm with the torch, magnetic base, and wire feeder was too cumbersome to be moved

around safely, except between adjacent jobs. A handling aid was designed which would assist in lifting and placing the robots and also act as a base for the robot controllers, power packs and associated hardware, thereby extending the operational area of the machines from a 30m radius to an entire unit assembly bay (Figure 8).

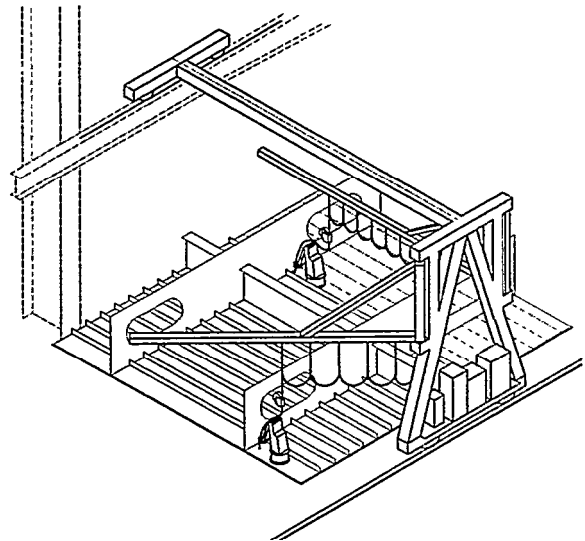


Figure 8. Robot Handling Aid For Vertical Access

The size and characteristics of the robot operating envelope, together with the size and shape of the robot arm dictate how effectively a robot can be applied. Generally speaking, the fewer the number of controllable axes, the greater the limitations. It is the relationship between the size of the repeating structural elements to be welded and the robot operating envelope which determines how effective the robot will be in a particular application. (For example, frame spacing compared to arm outreach at a particular stand-off distance from the workpiece). This relationship also depends on the particular welding consumables in use, as tolerance to changes in torch angle vary from one wire to another.

It was found during trials at British Shipbuilders that modification to the welding torch shape enabled the robot to access more intricate structure without interference, although the structural configuration of the ferries under construction was at the extreme lower limit of the M5030Z's capabilities. The auxiliary 'twist' axis was only found to be necessary in a very small number of cases, but nonetheless was regarded as

essential. A sixth controllable axis, in the form of a third wrist axis, would have permitted greater flexibility in choice of consumables, and would have reduced programming times.

Design For Production

In many cases, a design which may be manufactured with difficulty by traditional methods, will be impossible to produce using robotics. The use of robotics therefore focuses attention on detail design for production. The principles of standardization and simplification are particularly important for automated manufacture. At British Shipbuilders, for example, analysis of conventional structure showed that significant improvements in productivity, both with and without robots could be made by standardization of collars to only 9 designs. Additionally, the three-quarter collar in use was found to be impossible to weld by robot. Further investigation showed that considerable difficulty was experienced in welding these manually, leading to poor productivity and excessive rework.

There are certain design features which have a major bearing on robotic production but are of limited importance for non-robotic production. (For example, frame spacing). Extensive trials were undertaken to determine and quantify these features with respect to the limitations and capabilities of the M5030Z machines.

Quality

The initial application highlighted the need for upstream process control as the robots were not as adaptable as a human welder in respect to the quality of work presented to them such as gap size and edge preparation. This actually helped many employees to grasp the concepts of internal customers and Total Quality Management. Steps were then taken to modify upstream processes to reduce the variation in output. Use of the robots for butt welding at the hull construction stage would have imposed still greater demands on the control of the various production processes, and preparation for this application would be required in conjunction with extensive training in the principles of quality assurance. It is highly likely that these measures would have resulted in productivity improvements in themselves.

The quality of welds produced (given acceptable workpiece quality) was found to be exceptionally good (Figure 9).



Figure 9. Robot-Welded Collar

Industrial Relations Aspects

At first, shop floor employees were cautious of the prospect of a robot carrying out mainstream production welding. The attitude of the labor union for a short while prior to delivery was that the robots represented a threat to employment. Once the machines had been set up and were operational, this attitude disappeared, because of the physical size of the robot arm. The reality of a portable arc welding robot obviously did not match the pre-conceived ideas held by many people, based on myth and television programs about automated production lines. Throughout the project, the development compound was left open so that no mystique developed amongst shop floor personnel.

Extensive efforts to maintain communications with all employees resulted in an acceptance of the robots within an unexpectedly short period of time.

One aspect which gave some cause for concern was the machine monitor function. This measures usage in terms of the number of arc-ons, the total arc-on time, etc. This was viewed with suspicion by some union members as the exact amount of work carried out by each robot (and therefore each robot operator) could be monitored daily. As, at that time, there was very little accountability for progress at the shop floor level, this was viewed as a major change in management style.

Adaptive Control

With existing ship structures, it is not considered possible to universally apply an arc welding robot with less than six controllable axes and seam tracking hardware attached to the welding torch. In many cases, it was found that in order to access a joint with an acceptable torch angle and stickout, the torch would be almost touching the structure. Therefore, for a welding robot of the M5030 type, the only practical method of tracking a joint would be a suitable 'through-the-arc' technique in combination with a synergic pulsed power source.

A number of mock-ups were welded without seam tracking and the resulting weld quality was poor. A lack of seam tracking could, to a certain extent, be compensated for by the apposite use of touch sensing. However, touch sensing is time consuming to program and to effect.

The majority of welding robots available incorporate adaptive controls developed with the main users in mind. The specific needs of shipbuilders are not generally a concern for robot manufacturers, and hence software which is designed for use downhand on clean, unprimed steel may not operate correctly in a multi-positional shipbuilding environment.

Certain software functions available on the Hitachi M5030 range were found to be of limited use for shipbuilding. The 'Co-ordinates Translation' feature allows spatial distortion in a variety of forms (e.g. mirror image, uniform size change, non-uniform size change, angular distortion), but was only of interest for mirror imaging of offset bulbs. The various tasks involved in co-ordinates translation took almost as long as re-programming from scratch due to the difficulty in establishing accurate, fixed reference points.

A similar problem was experienced with regard to the 'Displacement Correction Function' (DCF). This function is designed to enable the robot to re-orientate itself after being moved from one job to another. Reference points are re-taught so that a rotational shift of the program geometry can be carried out. This requires that the robot be manually driven to both reference points which is very time consuming, and inaccurate unless lighting conditions are very good.

Setting bars which jig the robot into position against two reference surfaces were therefore designed.

These permitted reduced set-up times from those required when using the DCF.

Choice Of Consumables

The following points are of particular importance when considering the use of a robot:

- deposition rates;
- weld quality;
- current density and current ranges;
- effect of changing consumables on calibration of the seam tracking system;
- slag properties (can a weld be carried over slag and can an arc be struck on slag?);
- tolerance to change in torch angle; and
- effort involved in establishing parameters.

CONCLUSIONS

Design for production is of primary importance to any successful shipbuilder. If robot-arc welding is to be successfully implemented "design for robots" will also be essential. Robot systems cannot be effectively installed as "after the event" bolt on productivity improvement hardware but must be considered at the earliest stage of the ship steelwork design activity.

Standardization of the internal detail topology throughout a ship, and where possible between ship types, together with the reduction in variability of material types and sizes are probably paramount. The robot system's operational envelope should be recognized as a ship design criteria (6).

If "teach to learn" programming is to be employed this must be undertaken off line since it is very time consuming. Direct off-line Numerical Control programming via computer-aided design input would appear to be the direction in which future development should concentrate. However, positional arc welding is a complex process to automate since the constant compensating adjustments undertaken by a manual welder ideally must be replicated by real-time dynamic feed back within the system. Visual weld line fit up assessment is one area receiving much research attention which will almost certainly result in larger and more complex robots of increased first cost and reduced operational dexterity, certainly within the

foreseeable future. The alternative now is to exercise tight dimensional statistical control to the production of all component parts, minor sub and major assemblies to be robot welded to present a workpiece which is sufficiently consistent to allow existing blind welding be performed.

Consumables should be selected to give the best compromise between speed and ease of welding and acceptable quality standards. Consumables should also include or take cognizance of the shop primer used within the yard. British Shipbuilders experience points towards the inorganic zinc silicate primers as probably being the most weld process friendly although it is recognized such primers can cause problems in their own right.

The Portable Arc Welding Project did not produce the hoped for result. The M5030Z robots proved not to be suitable for production as intended. The barriers to be overcome relating to use of the seam tracking with consumables and primers required to produce acceptable welding quality eventually proved insurmountable. They did serve to indicate, however, the true latent productivity potential resident within arc welding robots and that, given the economic need, all encountered problems would be successfully overcome.

However the next generation of devices will need to be lighter and even more compact if the maximum benefits of the portability are to be exploited.

In summary, portable arc welding robots definitely have the potential to become shipbuilding tools and an effective means to increase throughput and profit. However, it is crucial to get the fundamental shipbuilding processes under control before robots are considered as a means of improving performance.

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Maintaining the Shipbuilding Technology Base - Looking at Other Markets

IIIA-

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ABSTRACT

This paper introduces for discussion the need and opportunities for shipyards to diversify into new areas of business. The need for diversification results from reductions in defense spending and the difficulties U.S. shipbuilders are having in gaining new orders. Shipyards have unique abilities that can be competitive strengths in other markets. Among these strengths are the ability to handle large, complex projects, the range of skills among their work force, and their proximity to water transportation facilities. Examples of shipyard participation in new markets demonstrates these strengths. Other markets addressed in this paper serve the utility and process industries, and the opportunities to participate in energy resource research and development.

INTRODUCTION

The intention of this paper is to initiate discussion on ways of using the shipbuilding work force and facilities to supply products and services to other markets. By doing so, the U.S. ship production base can be maintained and the process of lowering costs and improving efficiency can continue.

The military successes and difficulties during the Gulf War demonstrated the need for a strong sealift and naval capability. Recognizing this, it is a national security issue that a strong U.S. shipbuilding base be maintained. With budgets declining and technology changing, there is the need to keep shipbuilding costs under control. It has

been a government policy that competition among shipbuilders would insure lower costs and improve productivity.

Domestic commercial shipbuilding has all but ended. The notable exception is Matson's acquisition of a new containership from National Steel and Shipbuilding. Forecasts for the future suggest that the market may improve as older tankers are retired and new mandates for double-hulled ships come into play. There are, however, alternatives to building new tonnage for domestic trade. Further, today's charter rates will not support additional new buildings (1).

A lament from shipbuilders has been "how can we become more productive if there are no ships to build?" As the domestic commercial ship market has declined and the Navy market has begun to shrink, this has become the rationalization for government supports for shipbuilding.

Most shipbuilders are narrow in their perspective seeing themselves as a single product class industry. Evaluating what a shipbuilder does gives insight into a number of functions they perform internally which can be transferred or used to supply products to non-shipbuilding related markets. This means that shipbuilders can look to penetrate other markets to supplement their order books.

Benefits of entry into new markets include diversification of a shipbuilder's project portfolio, and distribution of overhead across a larger range of products. Diversification into

markets that have either constant growth potential or a different business cycle would stabilize the builder's work force and lessen the current feast or famine business environment. Distribution of overhead costs over a number of products lowers project pricing for all products.

DEFENSE SPENDING

The next few years will be difficult times for defense related industries. Fewer dollars will be available for strategic systems. Production lines will be closing down and workers will be displaced.

Shipbuilders will be hard hit. It is estimated that the shipyard labor force will decline from over 100,000 workers to around 60,000 by 1994. The shipyard labor force is skilled but those skills are not directly transferable to other private sector industries (2)

COMMERCIAL BUILDING

Foreign yards have full order books, reflecting a current need for tonnage, but also representing the decline in building capacity as yards have been closed over the years.

Major U.S. yards, with few exceptions, are not involved in commercial shipbuilding. Those shipyards that do have work are relying on Jones Act constraints on shippers. This is simply because U.S. yards are not competitive with foreign builders, particularly Asian builders.

CORPORATE STRATEGIES

Shipbuilders have for the most part, been dedicated to a single business. That is they have concentrated on what they believe they do best, building ships. This strategy has significant strength in providing its adherents with a very clear purpose and direction, which makes a complex business like shipbuilding easier to manage. The managers have familiarity with the core trades and technologies. First hand experience and knowledge is used to make decisions.

As the market has declined, shipyard

strategies have changed. Over time, they have followed three generic strategies. As the shipbuilding market became smaller, shipyards first focused on the US market and competed to be the low cost producer in the industry. Secondly, those yards that could not compete on price tried product differentiation emphasizing quality or other attributes. Now, as a third strategy in an even smaller market, shipyards are focusing on narrow market segments. As a result they are becoming specialists in single product types.

All of these strategies have been encouraged by government procurement policies as they have become the only customer. Recent reductions in government spending have forced Electric Boat and Newport News to be identified as shipyards specializing, respectively, in submarines and aircraft carriers.

Some shipyards, as well as other defense related industries, are looking for opportunities to diversify away from U.S. Navy shipbuilding. Electric Boat, for example, is considering moves into commercial shipbuilding (3). But U.S. shipbuilders' inability to penetrate today's commercial market prevents them from being able to maintain a stable workforce into the foreseeable future. Shipyards like Electric Boat who have not done commercial work are at a competitive disadvantage since little of their technology and experience is directly applicable to commercial ship construction (4). Alternative markets must be sought.

WHAT BUSINESS ARE WE IN?

Shipbuilders have unique strengths in comparison to other businesses. The most notable is their ability to deal with large sizes of products. Where other businesses measure their product in pounds, shipbuilders measure theirs in tons.

Shipbuilders are used to dealing in large numbers of constituent parts. Coordinating the procurement and logistics for all the parts that go into a ship is a monumental task. This includes the quality control, financing,

and engineering of these pieces.

Ships have been likened to floating cities. In fact all the aspects of a city are represented. One significant difference, however, is that a ship is designed for a specific mission. All the subsystems are integrated to fulfill this mission.

A ship built for the private sector is a revenue generating entity. There is an advantage to an owner who can get his ship producing first. This means that to be competitive in the market a ship builder must not just be good at moving the iron, but also move it as quickly as possible. For the ship owner, time is money both in terms of revenue production and in time value of capital.

Shipbuilders are providers of products that can be classified as industrial goods. They are providers of manufactured parts such as component piping, and capital items, in this case the ship itself. They are also providers of services. These are procurement, engineering, and quality assurance.

If one were to look at shipbuilders in the abstract it would be to see them as diverse manufacturing and construction operations. They could be perceived as consortiums of many small companies tied together to produce a common product.

By looking at each subunit of a shipyard as an independent business, opportunities to compete in smaller markets may be identified. By looking at the ability of shipyards to plan, engineer, and manage large scale, complex projects we may identify opportunities in markets that require those abilities.

In other periods of downturn, shipyards turned to other markets to sustain themselves and survive. During such a time after World War II, Newport News built railroad cars. At the same time, Electric Boat built truck bodies and automatic bowling pin setters. In general, they capitalized on their structural steel abilities. Shipyards are now in a position to compete in "outfitting intensive" markets. Carson and Lamb suggest this as a competitive strength for competing with European

and Asian builders (5).

In other countries, shipyards are part of the heavy industrial base and are more diversified than those in the United States. For example, Mitsubishi Heavy Industries uses their shipyards to fabricate and assemble subunits for power plants. As part of the heavy industrial base, shipbuilding is part of a coherent national industrial policy. Japan, as part of their industrial policy, has been phasing out shipbuilding along with other declining industries (6).

OTHER MARKETS

The U.S. is in need of infrastructure development. Part of this is an ever increasing need for electric power. The U.S. market for electric power has shown a minimum annual rate of growth between 1% and 2%. From the 1950's through the 1960's this rate was considerably higher as the U.S. population and industry grew. This growth in demand prompted utilities to add generating capacity. In the 1970's and 1980's, demand dropped to it's lowest rate of growth, saddling utilities with excess generating capacity.

Electric Utility Construction

Over the next 10 years it is expected that the power market will grow at rates higher greater than 2 percent. Current forecasts indicate utilities have used up the excess generating capacity and are approaching their limits to handle peak load demands. This makes addition of new capacity necessary (7). The need for power is significant enough that there are some in the industry who are predicting a resurgence of nuclear power, particularly with new high temperature gas cooled reactors (8).

Clearly, construction of additional power generating capacity will be an expanding market. As such, entry barriers to different levels of the market should be fairly low. That is, in a growing market there is room for all the players.

Prefabrication and Modularization in Heavy Construction

Utilities and other customers for heavy construction projects are putting a strong emphasis on shortening construction schedules and reducing overall project costs. Construction companies are finding that prefabrication and modular construction are techniques that can give them a competitive advantage.

The major factors driving modularization in heavy construction are the high costs of site labor and construction capital. By moving work off site, companies use less expensive labor. By shortening construction time, the construction company reduces capital costs and provides a customer with quicker revenue generation.

There are other factors that drive an interest in modularization. The geographic location of a construction site can make traditional construction techniques impractical and prohibitively expensive. A construction site may be constrained by limited storage and lay-down space. This is most common with additions to old facilities or reconstruction and refurbishment projects.

Heavy construction companies have used preassembly and modularization in the past. Preassembly is distinguished from modularization in the following way: preassembly assumes that component parts are available and can be assembled on the ground or near the construction site then put into place. Modularization (or prefabrication) involves advanced planning and engineering to allow vendors to assemble large blocks of components in their shops, then to move these to the site and into their final erected position.

Foster Wheeler has been prefabricating portions of process plants and have been able to make a trade-off of reduced erection/site costs for increased transportation and shop costs netting out to lower overall project costs. Foster Wheeler has found that these benefits only accrue if engineering is advanced in the project schedule, and if there is tighter control of material procurement against cost and schedule goals (9).

Two examples of modularization in heavy construction are the Zimmer nuclear-to-coal conversion project and the Murray hydroelectric station project.

The Zimmer generating station conversion used modularization of major components to reduce schedule time by one year. The constructor modularized the electrostatic precipitator system, auxiliary boilers, and steam turbines. The electrostatic precipitator was built in 30 modules, the largest weighing around 500 tons, in a shipyard in Mobile, Alabama (10).

The Murray hydroelectric station was built as a single unit 450 feet long, 146 feet wide, 121 feet deep, weighing 25,000 tons. The unit was erected at Avondale Shipyard from 200 pre-outfitted modules, then floated up river to its final position. The constructor credits the shipbuilding techniques employed by Avondale for making the project technically and economically feasible (11).

These two examples show that shipyards can bring their resources to bear on the heavy construction market. They have unique strengths that provide them with the ability to compete for parts of these projects. These strengths must be balanced against strategic weaknesses and threats inherent in penetrating a new market.

COMPETITIVE STRENGTHS FOR NEW MARKETS

A major shipyard strength is its flexibility. By virtue of having all the major trades and shops on site, shipyards are capable of a wide variety of manufacturing and construction tasks. Shipyard personnel have experience with boilers, control systems, gas turbines, diesel engines, and other complex technologies.

Location is an advantage. Because shipyards are situated with access to water transportation, they can move large assemblies or receive raw material by way of the most cost effective method of shipment.

The two factors above are amplified

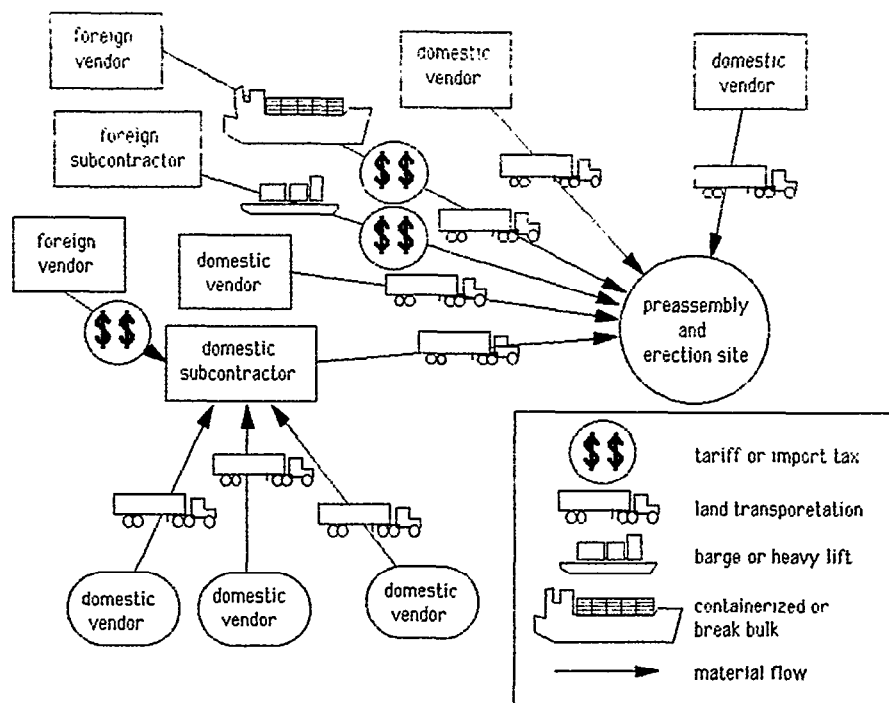


FIGURE 1

Typical flow of material and subassemblies from domestic and foreign sources to a erection site. import duties on foreign sourced material are incurred at each port of entry. Transportation and erection costs are also significant components of total project costs.

when shipyards are used inside a foreign trade zone. A foreign trade zone is a duty free area set up at a port of entry (12). Materials and products brought into these areas can be stored and assembled without incurring duties until they leave the facility. Raw materials or prefinished components can be received and assembled with advantages in reduced tariff costs .

Typical material flow for a construction project is diagramed in Figure 1. Material comes to the construction site from various domestic and foreign sources. There is considerable transportation cost associated with this flow. Further, import tariffs are charged at each port of entry.

The added cost of the import duties for finished products can make it more economical for work to be done in a U. S. shipyard rather than in a foreign facility. If the difference between foreign labor costs and U.S. labor cost

is less than the import costs, this can be a profitable opportunity.

Figure 2 shows how a shipyard could fit into this material flow. By focusing imported and foreign sourced material to one location, material can be consolidated and value added. The shipyard could assemble larger units for erection which could be transported by barge or other carrier to the job site. There is likely a savings on tariffs since they are paid on the assembled products rather than individual materials.

This material flow is not unlike that for building a ship except that the product is going inland instead going of to sea. There is a savings in transportation by virtue of the shipyard's location. Access to ocean loading and unloading facilities and the ability to handle heavy lift makes barge or ship modes an alternative to more expensive truck transportation.

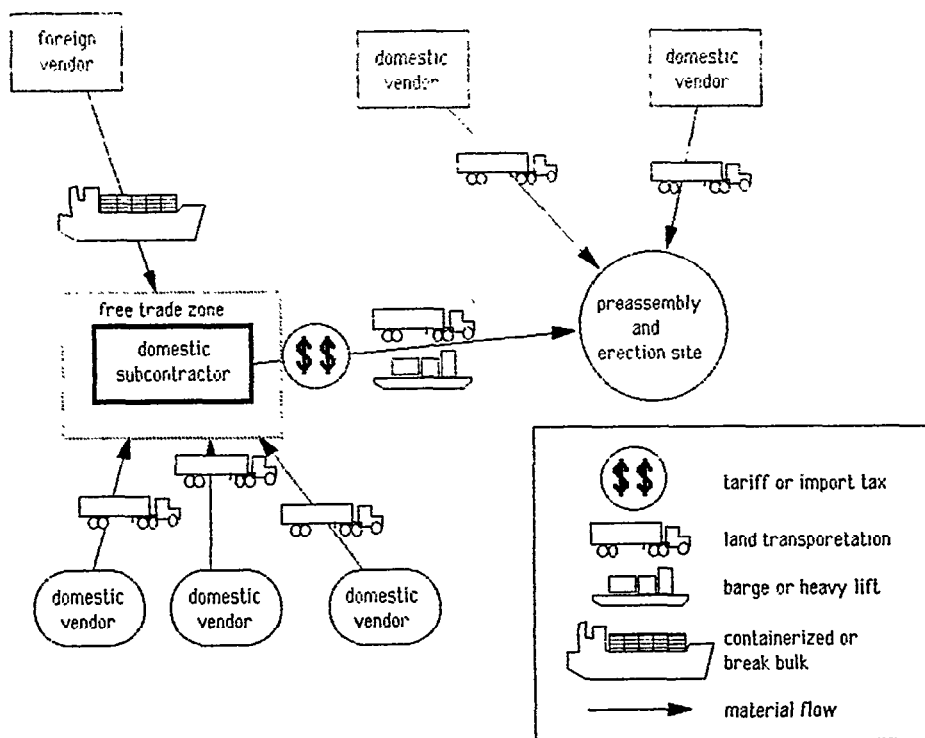


FIGURE 2

This illustration shows how a shipyard, as a domestic subcontractor whose facilities are established as a foreign trade zone, would function in as a supplier in a heavy construction market. Domestic and foreign sourced material would be delivered to a domestic subcontractor. The subcontractor then builds modular assemblies that are delivered to the erection site. The result is lower costs to the erector by virtue of lower import costs, lower domestic transportation costs, and lower erection costs.

Costs for trucking components to the job site are significantly greater than that for water transportation modes. 1981 figures for freight prices by mode show trucking rates to be 21 times higher than that for water transportation of freight (13). Since those figures were published, there is no indication that that ratio has changed.

Shipbuilders have a technological advantage. They have the facilities and personnel to support specialized needs of heavy construction.

The shipbuilding industry has been a primary source of skilled technicians and engineers familiar with steam boilers and nuclear systems. The complexity of combatant, ship control,

and propulsion systems has developed a work force that can provide expertise to civil, utility, or process plant construction.

WEAKNESSES OF THE SHIPBUILDING INDUSTRY

There are two major weaknesses that a shipbuilder must overcome. The first is the mindset of a defense contractor and of a subsidized industry. The second is a lack of familiarity with demands and nuances of a new market.

The biggest weakness that a defense contractor faces in this kind of diversification is eliminating a restrictive mind set dependent on government guidance and bureaucracy. Defense contractors must undo a lot of

overhead that has been built into their corporate structures and that are unnecessary to support a civilian customer.

Some shipyards have not been encouraged to work in the commercial and defense areas simultaneously or to diversify their product base. In some cases, notably Electric Boat, they have been discouraged by government representatives from doing so (14).

FOREIGN COMPETITION

A major threat in the heavy construction industry is the entry of foreign firms. Japanese and European firms have already recognized the growth potential of the U.S. power market. Foreign firms are entering the market using acquisition, an example being Asea Brown Boveri's acquisition of Combustion Engineering.

Foreign firms are not a direct threat to a shipyard working as a vendor to the constructor. However, if the transportation and tariff factors are neutralized by lower labor costs and higher productivity of foreign vendors, then shipyards can be forced out of the market. This requires that U.S. shipyards be cost competitive and that they improve their productivity.

ENERGY RESEARCH AND DEVELOPMENT

Carson and Lamb conclude that government sponsored research and development is a key factor that has given foreign shipyards competitive advantages in the world shipbuilding market. Carson and Lamb recommend that the U.S. government should fund more research and development (R&D) of promising marine technologies. This year, the U.S. government is budgeting \$2.45 billion for energy R&D and \$1.53 billion for transportation R&D (15). It makes sense to try to get the most for the R&D money that is out there.

Coordination of projects among the Department of Defense (DOD), the Department of Energy (DOE), and other government agencies would provide more efficient use of funds. This is a potential market for shipyards that have extensive experience in working on

government contracts, and turns what is a liability in commercial markets into a competitive strength.

DOE's current long ' term plan involves technologies for fuel cells, advanced nuclear reactors, advanced diesel engines, advanced batteries, alternative liquid fuels, and superconductivity, (16) that will be of interest to ship owners and builders in the 21st century.

Studies of fuel cell technology in marine applications have been sponsored by the U.S. Navy (17). Fuel cells use a chemical process to convert a hydrogen source and oxygen into electricity releasing high temperature steam and carbon dioxide as byproducts. The process has a conversion efficiency of between 40 and 60 percent. When the steam byproduct is utilized to mechanically generate power, efficiencies approaching 80 percent can be achieved.

As ships become more automated and capable, power requirements become important design considerations. On specialized ships, for example cruise ships, this has been a reason for using diesel electric drives. Studies performed for the Navy indicate that fuel cell technology may be a viable alternative to gas turbines or diesel engines, since their higher efficiency reduces fuel consumption.

A number of demonstration projects and developmental work for fuel cell technology are being funded as part of the DOE's plan supporting President Bush's National Energy Strategy. If shipyards are involved in development of fuel cells and other new technologies, they would have a step along the learning curve when they are used in marine applications.

CONCLUSION

Shipyards should look to expanding their businesses into non-marine heavy construction markets. Where they may not be able to take on whole projects, they can function as vendors to those in the utility or process plant construction industry. Shipbuilders have competitive strengths that can allow them to to penetrate these markets.

Among shipbuilders' strengths are their locations, facilities, and experience with advanced technologies.

There has been no sentiment in the Reagan or Bush administrations toward subsidizing industries, however R&D funds are being budgeted for energy and transportation (18). If shipbuilders' see themselves as part of the larger U.S. heavy industrial base, they can begin to share in development of new technologies that will give them a competitive edge in the shipbuilding market of the 21st century.

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Maquiladora Operations for Shipbuilding

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ABSTRACT

The maquiladora program was established by the Mexican government to encourage foreign investment and promote industrial growth. The success of the program encourages more and more participation each year. The low cost of labor in Mexico has attracted companies in all types of manufacturing in the United States with the exception of shipbuilding. With the focus on the domestic shipbuilding market over the last 25 years, U.S. shipyards have lacked the impetus to establish a maquiladora operation. The world market for shipbuilding has been steadily improving, while the U.S. domestic market has been steadily decreasing. The opportunities for U.S. shipyards to focus their strategies on the world market may not get any better. By understanding the complexities of establishing a maquiladora operation and then integrating the operation into its overall production plan, a shipbuilder can begin to realize that large labor cost savings are possible.

INTRODUCTION

When a labor source exists on our southern border that costs less than one third of the existing labor in U.S. shipyards, why is it not being used? What is preventing U.S. shipbuilders from taking advantage of the maquiladora program that has been in existence since 1965? If the answers to those questions were easy, there would not be any need for this paper. In fact there are many economic and political reasons why the lower cost Mexican labor has not been used. However, the industry's focus on the domestic shipbuilding market is the single most probable cause. Competition for the Navy and U.S. flag construction programs have absorbed management's attention to the point that the complexities of using a foreign labor force have discounted its consideration. The changing picture of the world shipbuilding market and the potential cost savings associated with using a maquiladora operation to build ships in the United States are now worth

refocusing a shipbuilder's market and operational strategy.

"Maquiladora" is an extension of the name "maquilala" that was given to merchants in colonial Mexico who retained a portion of the product that they produced as payment for their services. Today, a maquiladora is a plant in Mexico assembling components of a product that will eventually be marketed and sold in the United States and/or throughout the world. It is also the overall operation of transporting materials from the U.S. to Mexico, assembling the components and then transporting the completed units back to the U.S. for sale. The operation has many forms and represents many national and international policies. The success of the maquiladora operations have made a dramatic impact on the economy of Mexico and improved the prospects of the free trade agreements between the United States and Mexico. For over 25 years manufacturers in the United States have been able to retain or increase their market share both domestically and abroad by taking advantage of the low cost labor market in Mexico through various forms of maquiladora operations.

This paper seeks to establish that a maquiladora operation is a viable means of lowering the cost of shipbuilding and changing the market place for U.S. shipbuilders. The challenges that face the shipyards as the domestic shipbuilding market shrinks and new opportunities open for a global shipbuilding strategy will be used as the framework for the discussion. The structure, related costs and role of a maquiladora as part of a shipbuilder's organization will be used to highlight the complexities associated with establishing an operation in Mexico. Finally, we will present a means of estimating the cost savings that can be expected by the use of a maquiladora. The example illustrates how a hypothetical shipyard can achieve a 25% savings in labor costs.

THE WARNINGS ARE CLEAR

It is becoming increasingly apparent that U.S. shipyards must be able to compete in the foreign market in order to survive. This means that they will have to find a niche market for a special type of ship, develop a much higher productivity, or reduce labor costs drastically. Other industries have turned to maquiladoras in order to cut their labor costs. Except for isolated examples, shipyards have failed to take advantage of this opportunity.

Since 1965, while other industries have developed over 2,000 maquiladora operations, the market for commercial shipbuilding in the U.S. has continually shrunk. A projection two years ago estimated that the size of the likely available commercial market for U.S. shipyards was only 7% of the potential market and that did not include selling to any foreign shipowners (1). Although that may be a minimally adequate market for the next 5 to 10 years based on the capacity of the remaining U.S. shipyards, it is unlikely that it will carry the industry into the twenty-first century. More recently, there have been several warnings issued to the U.S. shipbuilders. Some have been direct like the statement made by Tom Duncan, Managing Director of A&P Appledore (Falmouth, UK):

"This is the biggest and most powerful country in the world, but it is also the most insular. You have got to get out and hammer the market overseas. You have got to think outside of this country, not within it. If you don't stand on your own two feet, YOU will perish." (2)

Indirectly, the large cuts in the Navy's new construction programs can be taken as a very significant warning.

Other warnings have been in the form of U.S. shipowners making decisions to use service life extensions instead of paying the high prices for new construction ships.

These warnings have not gone unheeded. The industry is clearly making attempts to counter the downward trend, and everyone knows that defense dollars will not sustain the shipyards as they have in the past. Long range strategies have to be established to take advantage of current domestic and foreign market projections. When the requirements for establishing and using a maquiladora are analyzed, it becomes clear that, although there is a great potential for reducing labor costs, the substantial start-up and operating costs must be considered as part of a long range shipbuilding strategy. There is a perception that a shipyard could make use of the low cost Mexican labor on a short range project to cut its production costs. While there are several subcontractors with maquiladora operations that can provide -selected ancillary components such as deck fittings, doors, deck gratings and some outfitting equipment, we plan to address this paper to the shipbuilder who wants to develop a more comprehensive strategy to compete as a global enterprise.

OPPORTUNITY TO ENTER THE GLOBAL MARKET

The protected domestic market has been the principal source of new construction orders for U.S. shipbuilders for decades. With the decline in commercial orders since the early eighties, the increased competition among the shipyards for the Navy and U.S. Flag ships required all yards to continuously update their operations. The yards sought new ways to cut unit production costs including establishment of new production control methods, incorporating standard designs, implementing the processes of group technology, replacing out dated

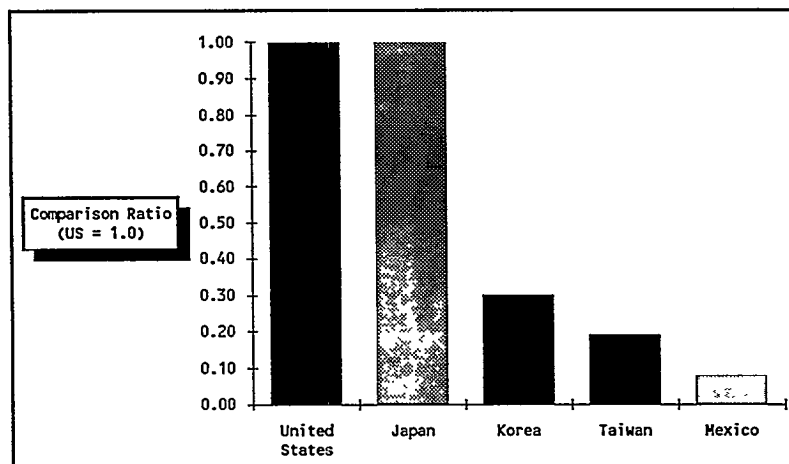


FIGURE 1
Wage Comparison

equipment with modern labor efficient machinery, and increasing the capacities of drydocks, cranes, and fabrication facilities. By the end of 1990 the surviving major new construction shipyards have significantly improved their competitive position with the Europeans with regard to productivity and capacity (1). Furthermore, the cost of labor differential has improved to the point where only the very low labor rates of the Far East shipbuilders remain below the average of U.S. shipyards (Figure 1).

Combined with the reduced demand for new ships in the 80's and the steady increase in the price of ship construction in the foreign shipyards, the downsizing and cost controls imposed by the ever narrowing domestic market have helped the U.S. shipyards to reach a better position in the world market. However, even though the continuous focus on the domestic market has helped to stabilize the cost of new construction, it still costs too much to have a ship built in the United States.

Recent projections indicate that there will be a new surge in the demand for replacements of Jones Act ships over the next ten years. This increase in the domestic market will coincide with a world wide increase in new shipbuildings. The annual projection of replacements for Jones Act ships represents only 2% of the projected world wide market. It also represents about 45% of the current commercial shipbuilding capacity of the U.S. shipyards. But, what appears to be a good opportunity for the shipbuilders has yet to materialize in orders on the books for the U.S. shipyards. New construction prices are still the major constraint to getting order books filled. Reduction of labor costs through the use of a maquiladora may provide the opportunity to bring the cost of new construction down.

Global Enterprise

Anticipating the capture of only 2% of the world market that satisfies less than 50% of the industry's capacity offers only slight improvement in the U.S. shipbuilding market. Expansion of the shipbuilding market will require U.S. shipbuilders to become global enterprises. Companies that undertake activities anywhere around the world in order to maximize their performance and enlarge market share can be considered global enterprises according to Robert B. Reich of Harvard University. He recently wrote that:

"The new global manager's job is to exploit the opportunities created by the high-powered technologies of worldwide communication and transportation and by the relaxation of national controls over cross-border flows of capital." (3)

As a result of companies expanding their operations into the global market, the new boundaries for world economy are corporate and not geographical. This premise is illustrated by examples of corporations that have decentralized their operations to take advantage of the particular strengths of various global regions.

- Boeing's next airliner will be designed in Washington state and Japan and assembled in Seattle, with tail cones from Canada, special tail sections from China and Italy, and engines from Great Britain.
- The Mazda ME-5 Miata was designed in California, financed from Tokyo and New York, its prototype was created in Worthing, England, and it was assembled in Michigan and Mexico using advanced electronic components invented in New Jersey and fabricated in Japan (3).

In each case the products are broken down into cost elements and the components produced at the most cost effective location. For a global corporation this means establishing corporate entities in countries where the resources offer the best services for the lowest cost. The tendency is to site high value-added activities at the location where it is most cost effective.

Because of rapidly changing world political and economic events, every business publication today has at least one article related to the expansion of global corporations. The extent of the expansion is illustrated by the fact that when the foreign sales of U.S. owned companies are calculated against the total purchases by Americans of the products of foreign owned companies, America's trade deficit turns into a net surplus (3).

Competitive Advantage

Ships are not built on assembly lines like automobiles, but shipbuilders should look closely at the world wide organizations that have been established by the car makers. The U.S. automobile manufacturers have been able to retain their market share by moving operations such as engine production to maquiladoras. The Japanese have strengthened their market share by establishing assembly plants in the United States. Regardless of the product, a company that has a market outside of its own country must establish a long term global enterprise strategy. A key element in that strategy is removing the old ideas of centralization of control. The successful global corporations have decentralized their operations and repositioned their subsidiaries in other countries. Their strategies focus on placing each component of the operation

at a site where it best serves the overall company goals.

A global thinking shipbuilder could conceivably locate corporate headquarters to better service their customers, accomplish engineering at a site that offers both expertise and reduced overhead costs, prefabricate components in a region where labor is plentiful and cheap, assemble and launch ships at the traditional shipbuilding site, and complete outfitting in a region where labor productivity is high. While a complete reorganization of a U.S. shipyard to this extent is unlikely in the near future, the fundamental aspects of a global enterprise should be included in the long range corporate strategy.

Launching a new long range strategy to lower the cost of ship construction by as much as 10% will give the shipyard a new competitive advantage. It will be necessary to gain an interim advantage over other U.S. shipyards to win the limited number of domestic contracts. This interim advantage will provide the opportunity to expand the operation to the global market.

CHALLENGES TO OVERCOME, DOMESTIC CONSTRAINTS

With the price of foreign shipbuilding rising faster than the price of U.S. constructed ships the opportunity for U.S. shipbuilders to enter the world market is good. The combination of projected saturation of the low-cost foreign shipbuilding capacity in the near future and the major productivity improvements in U.S. shipyards should make prospects better than ever. There is also a good opportunity to use the current requirements for replacement of U.S. Flag vessels as a spring-board to further reduce building costs. A.E. Gibson proposed government assistance to build a series of petroleum product carriers to replace approximately 55 tankers engaged in Jones Act trade (4). It will probably be necessary to give the U.S. shipbuilding industry that kind of boost in order to be able to implement a global enterprise strategy.

Jones Act Ships

Although a maquiladora operation may have been considered by some of the U.S. shipyards in the past, the focus on the domestic market for Jones Act ships and U.S. Navy construction precluded any implementation. The regulations for building Jones Act ships have been too restrictive to warrant the effort. These regulations are quite specific; the work must be done in a U.S. shipyard. The major portion of the hull and superstructure must be fabricated and assembled in the United States. However, the current interpretation of the regulations may allow portions of the

ship related to the secondary structures to be manufactured by a maquiladora.

Secondary structures may be defined as any item that does not affect the structural or watertight integrity of the vessel. This could possibly include equipment, furnishings, non-watertight doors and windows, stairways, railings, miscellaneous deck fittings, joiner bulkheads and machinery foundations.

The federal regulations also restrict the size of the portion of the ship that is foreign built. If the weight of the foreign built components represents a "considerable part" of the overall weight of the structure then the ship will not qualify for coastwise trade. However, there is no established standard for the ratio. The Coast Guard Vessel Documentation Division considers each case uniquely. In the case of whether a vessel was rebuilt at a foreign shipyard, the Documentation Office recently considered hull replacements of less than 1% of the total hull steel to be small enough that it did not qualify as a rebuilt vessel (5). However, the ruling implied that each case would be ruled on its own merit and another request for documentation with only 1% of the hull weight built overseas may be denied.

As the regulations are currently interpreted for Jones Act vessels, it will be difficult to use a maquiladora for any thing other than some of the secondary structure. The amount will have to be determined on a case by case basis. However, it seems that a case could be made to utilize a maquiladora to construct structural subassemblies as long as the final assembly and erection of hull and superstructure modules were done in the U.S. shipyard.

U.S. Navy Construction

The other source of work for the shipyards has been the U.S. Navy. While the Navy contracts are governed by the Buy American Act, security requirements and convenience have been principal reasons for not using maquiladoras on the government contracts. For the last ten years all yards have focused on winning the numerous Navy contracts. The government has been willing to pay the high labor and overhead rates in the U.S. yards. Contract modifications are negotiated at labor rates that allow the shipyard a reasonable profit. The Navy contracts, particularly the fixed price work, have promoted many cost cutting measures in the shipyards, but these measures have been aimed at finding ways to get below the costs of another U.S. shipyard. While the efforts to improve productivity and facility efficiency have helped, they have failed to reduce the costs enough to allow access to the foreign markets.

Opportunities for Maquiladoras

For a U.S. shipbuilder to invest the time and capital to develop a maquiladora, it will be necessary to include both foreign and domestic markets in the shipyard's long range strategy. Likelihood of success in the domestic market can be improved by the ability to use the maquiladora to build components for Jones Act ships. Such success will better position the shipyard to accomplish its goals in the global market. Once the maquiladora is incorporated into the long term operation of a shipyard, a distinct competitive advantage will have been gained over other U.S. yards. The commitment to establish a maquiladora will involve considerable risk, planning, legal transactions, and financial obligations. On the other hand, the success of other industries in the maquiladora program and the potential for substantial cost reductions make the program an attractive solution for both ship owners and shipyards to reduce the cost of shipbuilding in the United States.

From a technical perspective, shipyards should be able to make extensive use of a maquiladora operation. Since approximately one third of the cost of building a ship is labor, any scheme that reduces the cost of labor by over half will be beneficial. A maquiladora would fit into a ship construction operation in the same way that U.S. shipyards now utilize other shipyards and major subcontractors to build subassemblies of ships. The principles of block construction require the shipyards to develop material flow plans within their facilities that optimize the transport of blocks and sub-assemblies to the erection site. Applying these production planning techniques to a maquiladora operation should require minimal change to the current advanced shipbuilding procedures that have become the norm in all shipyards.

The opportunities for using a maquiladora are not unbounded. Many of the same reasons that faced other industries and probably have kept shipbuilders away still must be overcome.

Labor relations at home, initial investment costs and risks, and the anxiety of an unknown labor force have restrained corporate executives from establishing a maquiladora. Although these problems still exist, favorable conditions exist today that should ease the maquiladora process. More and more labor organizations are recognizing that the real competition in any industry is from overseas corporations and that the maquiladora program has established a good reputation in the last ten years as being a solution for industries in trouble. In most cases the U.S. based companies have been able to retain or even expand their U.S. work force by moving some of their operations to Mexico.

The decline of the shipbuilding industry is well recognized by workers and management, and shipyard labor has shown more willingness to accept new programs. By planning and presenting a maquiladora operation as part of the long term solution to the shipyard's workload, there is greater potential for improved workload and increased capacity when the cost of construction is competitive with other countries. The real opportunity for using a maquiladora for shipbuilding may be that there is no better time than the present to establish one.

MAQUILADORAS: WHAT & HOW MUCH?

For those who do not live along the southern border of the U.S., the term "maquiladora" may be new. However, anyone who has followed the plight of the automobile and other heavy industries over the last 20 years is well aware that they went to Mexico to seek ways to reduce their production costs. Ford Motor Company recently announced plans to spend \$700 million to expand its 9 year old motor manufacturing plant to increase capacity to 500,000 engines annually. General Motors will also open four new plants for its electrical subsidiary to produce automotive electrical cables (6). As Table I shows, heavy industry related work represents approximately 35% of the maquiladora operations. Companies in all fifty states now participate in the maquiladora program.

TABLE I
Heavy Manufacturing in Maquiladoras (7)

INDUSTRY	PERCENT OF ALL PLANTS	PERCENT OF ALL EMPLOYEES
Transportation Equipment and Accessories	9.5%	19.6%
Electric and Electronic Machinery Equipment and Apparatus	7.1%	15.6%
Other Heavy Manufacturing	18.4%	12.3%

Successful Program

The growth of the maquiladora industry reflects the commitment that the Mexican government has made to the program since it was first established in 1964. The objectives of the program were to create jobs for the areas of high unemployment that were affected by the discontinuation of the Bracero Program and to promote industrial development along the U.S./Mexico border. The new policies that promoted these objectives allowed duty-free import of equipment, materials, machinery and component parts for assembly or processing within a twenty-kilometer strip along the border, provided that all imported products were reexported.

Since the program's inception there have been several revisions. Maquiladoras are now exempt from the requirement of Mexican majority ownership and are allowed 100% foreign ownership. The original 20 kilometer area restriction has been lifted and maquiladoras can be located anywhere with approval of the Mexican authorities. Foreign technicians and managers are now allowed to reside in Mexico and customs procedures have been eased. New industrial parks are now promoted to entice more industries into the maquiladora program.

The U.S. tariff laws for lesser developed countries support the maquiladora program. By allowing preferential duty treatment for products from developing nations, the Customs Tariff Regulations give the maquiladora program a boost. The only duty charged for goods manufactured in a maquiladora is for the value added in Mexico. The value added is usually for labor, overhead, and profit margin.

Growth of the maquiladora program was slow at first. As Figure 2 shows, the program has accelerated since 1972 when the authorized zone was expanded to

allow establishment of plants in economically depressed areas. The steady growth has meant a growth in skill levels. Maquiladoras are now second only to the oil industry in Mexican exports. In 1988 the foreign exchange generated by oil equaled \$9 billion, maquiladoras \$2.3 billion and tourism \$1.6 billion (7).

The objectives of the Mexican government have been achieved. Over 450,000 jobs have been created, an industrial base has been established, and technology has been transferred. The Mexican government continues to seek greater use of Mexican sources for products, and it continues to simplify the process of starting and operating maquiladoras.

Despite its successes, there is still a perception within the U.S. that maquiladoras are only for low skill, highly repetitive assembly operations. In a recent editorial in the Wall Street Journal in support for the proposed Free Trade Agreement with Mexico, Rudiger Dornbusch, a professor of economics at Massachusetts Institute of Technology, noted that the low labor costs in Mexico reflect a low level of productivity and in some areas low quality (a). Unfortunately, these generalizations are often applied across all industries. If the productivity was truly as low as professor Dornbusch implied, then the maquiladora program would not be growing at the rate of over 10% per year. As demonstrated by the successful users of the program, proper management of the maquiladora can produce a high quality product from a very productive labor force.

Maquiladora structure

Ships are unique products that are built to very tight schedule. Even in a multi-ship building program the ship-builder will be time constrained to complete each vessel. It is important to

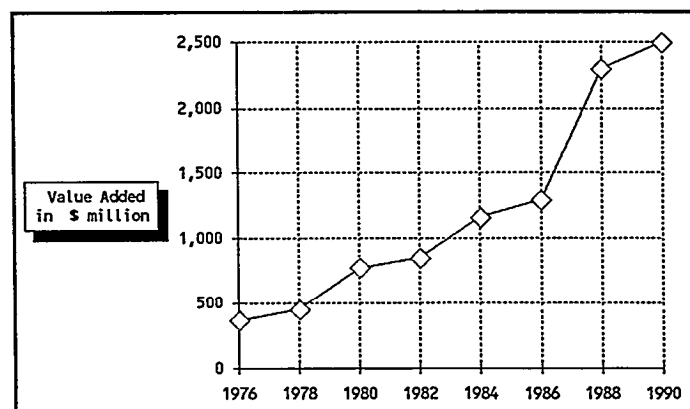


FIGURE 2
Growth of Maquiladoras (7)

maintain control over all aspects of new ship construction. This primary constraint will influence a shipyard to most likely consider full ownership of a maquiladora as opposed to using a maquila subcontractor or a sheltered maquiladora. of course the advantages and disadvantages of each type of maquiladora must be considered with regard to the existing shipyard's capacity and availability of capital.

Maquila Subcontractor. A shipyard may subcontract to a company that has a maquiladora operation. This is currently being done rather successfully on a small scale. To the shipyard there is not much difference from subcontracting to any other company. The maquiladora subcontractor will probably have an office or shop in the U.S. and a production plant in Mexico. They contract to provide the product as any other subcontractor, and the shipyard only has to carry out the normal inspection plan of the subcontractor's work. Although the shipyard will see a lower price from the subcontractor with the maquiladora operation, the difference will not be significant. After all, the maquiladora subcontractor will be pricing his work just below his competition operating in the U.S.

Using a subcontractor is the easiest way to take advantage of a maquila's low cost labor, and it has the fastest start-up to production work cycle. The subcontractor provides the maquiladora plant, labor force, and handles the import/export procedures. As with any other subcontract for ship construction, the shipyard or the subcontractor may provide the raw materials or components for the manufacturing process. The procedures for supplying materials, work schedule, and quality assurance requirements will depend on the work specification and the contract between the shipyard and the maquiladora. The shipyard only has to pay for the finished product while the subcontractor usually assumes most of the financial responsibility. Of course, the shipyard gives up some control of the production and must utilize its own management to ensure that the quality of the product meets the work specifications. The greatest disadvantage to subcontracting for maquiladora work is that the cost savings is the smallest of the three alternatives.

Sheltering. Using a sheltered maquiladora is similar to subcontracting, but the shipyard will be dealing directly with the maquiladora operation. In effect the middle man, in the form of the subcontractor's U.S. office or shop, is eliminated. Another way to consider sheltering is that the shipyard will specify the required work to be done in a maquiladora plant. A sheltered maquiladora is usually

established to provide assembly services for a variety of customers. Payment is usually based on piecework, hourly, per worker basis, or some other fee arrangement. Whether or not the shipbuilding industry can find a suitable sheltering arrangement in Mexico is unknown. Currently, sheltering primarily services the electrical and electronics industries where one shop may have several customers requiring similar worker skills.

Sheltering offers a way to start small and limit the legal and financial involvement of full ownership. The Mexican "partner" in the shelter arrangement handles the legal and financial requirements to establish and operate the maquiladora, while the shipyard has more input to the labor force and manufacturing equipment. However, as with subcontracting, the shipyard has limited control over the production schedule and must still share the benefits of the lower labor costs. In the long run sheltering may be more expensive than full ownership.

Full Ownership. In consideration of the long term strategy of using a maquiladora operation, a shipyard will probably establish that full ownership is best and has the greatest benefits. However, it requires that the shipyard establish a subsidiary as a Mexican corporation and satisfy all the requirements established by the Mexican government. The parent company assumes full control of the maquiladora and carries the financial burden of establishing the operation. The maquiladora is usually operated as a cost center to minimize the tax liabilities, and the parent maintains control of the profit margin. The maquiladora program encourages 100% ownership by the foreign company, and the real estate laws provide for direct land ownership or establishment of 60 year trusts for the land adjacent to the border or along the coast.

The disadvantages are similar to expanding an operation to a neighboring state in the U.S. It requires a long term commitment with the associated risks and visibility. The Mexican corporation is subject to all the Mexican regulations, permits, labor laws, and taxes. The shipbuilder must consider buying or leasing the facilities, importing the machinery, hiring management and work force, training the work force, and maintaining the plant and equipment. Although not necessarily a limitation to the primary function of the maquiladora for a shipyard, the maquiladora owned by a foreign company may be restricted to selling no more than 20% of its production in Mexico.

Cost Factors

The Mexican government has continually sought ways to improve the

TABLE II
Operating Cost Comparisons (7)

ITEM	MEXICO	UNITED STATES
Electricity	\$.035-\$.06/kwh	\$.07-\$.12/kwh
Water	90% of U.S. cost	100%
Natural Gas	65% of U.S. cost	100%
Gen'l Construction	\$10-\$20/sq.ft.	\$25-\$60/sq.ft.
Lease Costs	50-80% of U.S. cost	100%

maquiladora program and make it easier for foreign countries to take advantage of the low cost labor. Combined with favorable U.S. tariff regulations, they have successfully met their primary objectives for the maquiladoras. The Mexican regulations related to maquiladoras are very similar to U.S. federal and state corporate regulations. With the exception of the Mexican Federal Labor Law, the establishment of a maquiladora requires similar cost considerations as a company would face setting up a new subsidiary or division in another state. The following cost factors will become part of the overall decision for the establishment of a maquiladora. For some of the factors a definite dollar value can be established while others can only be treated subjectively as to how they will affect the cost of the overall operation.

Financing. The process of obtaining financing and considering the assignment of inventory and assets is similar to establishing any expansion program. Most financing of a maquiladora is done through U.S. sources with the parent company. It is difficult to get Mexican financing to establish a maquiladora because the assets are usually owned by the foreign parent corporation, and operating as a cost center, it will not show revenue. Since the hard assets are located in Mexico, another foreign bank will not usually provide financing. But opportunities are available for joint ventures with private Mexican corporations which can arrange financing through Mexican institutions.

Operating Costs. The cost of operating a maquiladora plant will usually be considerably less than operating a plant of similar size in the United States. Land prices, construction costs, leasing rates and utility rates which may often be less than half of similar costs in the U.S. are dependent upon the location of the maquiladora. The maquiladoras operating along the California and Arizona borders are seeing land values and lease rates comparable to the U.S. side of the border. The construction and utility costs for this same area are similar to the rates shown in

Table II which provides a comparison of the typical operating costs for a maquiladora (7).

Direct Labor Costs. The maximum number of straight time hours that an employee may work each week is 48 hours on the day shift, 45 hours on the second shift, and 42 hours on the night shift. Up to 9 hours exceeding these maximums require 200% premium pay and 300% premium pay for overtime exceeding 9 hours in any week. Most employers operate on five work days of 9.5 hours each day. The employees must be given one day of rest per week. The range of direct labor rates is presented in Table III.

Vacations and Holidays. There are 7 required holidays and the vacation requirements are similar to U.S. companies, except that employees must be paid an additional 25% of their regular pay during their paid vacations.

Bonuses. A year end bonus of 15 days salary must be paid each employee by December 30 of each year. In addition, each company is required to distribute 10% of its annual taxable income to its employees. First year companies are exempted from this requirement. The profit sharing bonus is required within 60 days of paying taxes. Since most maquiladoras operate as cost centers, an additional bonus is paid to supplement the profit-sharing distribution.

Social Security. The employer pays a registration fee of 16.6% of each employee's salary that is subject to social security. This fee relieves the employer for liability in connection with job-related illnesses or accidents, and provides certain medical and insurance benefits to the employee and his dependents.

TABLE III
Comparison of Direct Labor Rates (\$/Hr)

COUNTRY	UNSKILLED	SKILLED
Mexico	\$0.95	\$3.50
United States	\$7.00	\$15.00

TABLE IV
Maquiladora Tax Obligations (7)

TAX	RATE	APPLIED TO	REMARKS
Corporate Income	35%	Taxable revenues based on services provided.	Deductions similar to U.S. taxes.
Corporate Asset	2%	Assets recorded to maquiladora.	Depends on how parent assigns plant machinery.
Value Added	6-16%	Products & services bought in Mexico.	Goods & services used by the maquiladora.
Payroll Tax	1%	Total of salaries & wages paid each month.	Several Mexican states also levy similar tax.
Real Estate Acquisition	10%	Adjusted base value of real estate.	Adjustment based on minimum wage in district.
Property	Varies	Registered value of real estate.	Levied by Mexican states.
Individual Income	Varies	Taxable income.	Type of visa determines rate.

Housing. Employers must pay 5.22% of the wages to the Federal Workers Housing Fund to assist in providing housing for employees.

Bonding Procedure. The amount of the corresponding import duty and any fine or penalty that could result should the imported goods (temporary imports) not be returned within the authorized time period must be guaranteed with a bond. If the maquiladora establishes itself as financially solvent, temporary imports require a bond for 40% of the import duties and value added tax on the raw materials and components plus possible fines and surcharges; imported machinery and equipment require a 60% bond. The cost of a bond is usually 1% of face value. Payment of import duty may also be guaranteed by pledge of machinery and equipment or a mortgage of the real estate held by the maquiladora.

Taxes The Mexican tax requirements are similar to the federal and state taxes in the U.S. They can become significant expenses and must be carefully considered when structuring the organization of the maquiladora. Most parent companies organize the maquiladora as a cost center to minimize the income and corporate asset taxes. Corporate decisions regarding the relocation of managers, supervisors and technicians and the type of visas that they obtain will affect the amount of the individuals' income taxes. Table IV summarizes the tax obligations for a maquiladora (7).

Complexities

Labor Relations. The Mexican immigration law provides that no more than 10% of the work force may be foreigners, but exceptions have been made for maquiladoras. They may bring in an unrestricted number of foreign technicians, supervisors, and managers. The number of foreign hourly employees is restricted by the immigration quotas with the exception of employees brought in to conduct a training program. Visas for either temporary (six months at a time) or for permanent immigration of managers and dependents to live and work in Mexico are relatively easy to obtain.

One law, the Mexican Federal Labor Law, governs all labor matters. It regulates the employer/employee relationship and details minimum working conditions and benefits. Mexican federal and state labor boards have jurisdiction on all labor matters arising within their limits.

All employees work under a contract either as an individual or collective relationship with the employer. If the employer has not entered into a collective bargaining agreement with a union, each employee is automatically considered to have an individual relationship or contract with the employer. The relationship may either be temporary for a specified period of time or permanent for an indefinite period of time. If the relationship is not in

writing at the time of employment, a permanent relationship is assumed. The principal difference between the two relationships is that with a written contract for a temporary relationship, the employee may be terminated without justifiable cause and financial obligation. No written contract is required, but the Labor Law considers the employee to be under contract according to the law. Written contracts are highly recommended should disputes go before a Labor Board. (Generally, permanent employees terminated without justification are entitled to 3 months severance pay plus 20 days pay for each year worked. If dismissed for justified cause, the worker is entitled to accrued pay and unused vacation pay and seniority benefits.)

Mexican Unions. Mexican labor laws clearly benefit the workers. An employer must provide detailed documentation of reasons why a worker should be fired and will have to pay the worker severance pay. Labor unions exist primarily to negotiate wages and influence the Mexican Congress for labor related legislation. The strength of labor unions varies with the location of the plant. Unions are strongest along the Texas border. Experience in maquiladoras has shown that maintaining wages for skilled workers above the average for the area has improved performance and workforce stability.

Turnover. Turnover rates up to 35% have been experienced in many of the maquiladora operations. Many of the workers have come from the poorer interior sections of Mexico and after saving a little money quit the maquiladora and return home. There is also competition from other maquiladora operations. Often the workers view their job at a maquiladora as a way to learn a skill that can be used when they have an opportunity to go to the United States. Turnover rates of less than 10% are more common in the well managed, stable maquiladoras. To prevent high turnover rates, some maquiladoras have established strict recruitment policies. Experience at a maquiladora subcontractor providing secondary structural components to shipyards has shown that paying better wages has reduced the turnover rate. Furthermore, since most of the workers (welders and machinists) are male, there appears to be greater stability than in those operations which employ large numbers of women who often leave to take care of their families.

U.S. Unions. In response to a request from the AFL-CIO in 1988, the Wharton Econometric Forecasting Associates presented a study to the Secretary of Labor titled "The Implication for the U.S. Economy of Tariff Schedule Item 807 and Mexico's Maquila Program." The study quantified

several possible scenarios, including eliminating special tariffs for goods originating from developing countries (tariff item 807), for goods produced only in Mexico, eliminating tariff item 807 for all countries and eliminating the maquila program. Their conclusions were that both the maquila program and tariff item 807 benefit the U.S. economy by allowing lower U.S. prices and increased demand for U.S. manufactured components. It also found that the maquila program was continuing to achieve its goals of increasing the number of skilled Mexican workers and establishing new industries in Mexico. The study supported the premise that trade expansion means more jobs on both sides of the border (7).

It can be anticipated that shipyard labor organizations will generally express the same dissent toward a maquiladora operation that other unions in other industries have over the past 20 years. Organized labor have recognized the conclusions of the Wharton study that the use of maquiladoras has not been the cause of lost jobs. They have also recognized that without the cost savings offered by the maquiladora, their companies would probably have folded or moved to Southeast Asia, and they would be out of work anyway.

Again, shipyard management must look at the long range strategy for establishing a maquiladora. When the potential for new markets for the shipyard and expansion of the workload are considered as part of that new strategy, the maquiladora can be integrated into the shipyard labor force without reduction of the current workforce.

Mexican Customs Law. In Mexico a special customs regime governs maquiladoras. The Mexican customs laws allow temporary importation of merchandise that will remain in Mexico for a limited time for a specific purpose. Imports of raw materials and components are typically authorized for a period of six months, but extensions are easily obtained. The maquiladora must authorize a customs broker to process the necessary paperwork related to temporary importation of materials.

Returns and Re-exportation. According to Mexican law some equipment may be re-exported duty-free. This would include plant operating machinery and equipment being re-exported to the United States for repair or replacement. To qualify for the duty-free status the repair value must be less than 29% of the original amount imported under the maquiladora program.

U.S. customs Law. The Harmonized Tariff Schedule for the United States, implemented in 1989, strengthened the maquiladora program. In general only the value added to the product at the

maquiladora is subject to import duties. The Generalized System of Preferences (GSP) allows for certain products assembled in a maquiladora to qualify for duty-free entry if the value added to the product at the maquiladora is greater than 35% of the appraised value of the article at the time of entry into the U.S.

Logistics and Management. The logistics of transporting materials to the Mexican plant and the product back to the shipyard will probably be the biggest non-labor expense of a maquiladora operation. Since Mexican suppliers are limited (e.g., there are no suppliers of certified materials) most production materials must be transported from the United States. The additional requirements of clearing customs when crossing the border will cost up to an additional day of transportation time in both directions. Mexico only allows the U.S. truck trailers to cross to the maquiladora plants. While this minimizes the handling of the materials on the trailer, it still requires switching to a Mexican tractor and driver. Mexican trucking companies can deliver goods to anywhere in the U.S. within 25 miles of the border. The cost of using a Mexican trucking company is approximately the same as in the U.S. If the U.S. shipyard is located further than 25 miles from the border, it will be necessary for a U.S. trucker to pickup the assemblies at the border. Also, all oversized loads will have to be moved by a U.S. trucking company specifically licensed for that operation. Due to the anticipated larger size and special handling requirements, the shipyard will probably find that it is less expensive to operate their own hauling equipment.

The availability of experienced maintenance contractors in Mexico is extremely limited. Most maquiladora plant operators maintain full time maintenance crews to service their plant machinery. Power failures and disruptions of other utilities have received much notoriety for the new maquiladoras, but with the build up of the program the Mexican infrastructure has shown significant improvements in recent years.

Management of a new subsidiary can cause complications regardless of where it is located. A maquiladora has the differences in culture and language to offer new challenges to management. Although the Mexican government allows an unlimited number of foreign managers and technicians to live in Mexico, most maquiladoras use Mexican nationals for many of their staff positions. Early selection and training of Mexican management personnel will help to eliminate many of the start-up problems including the hiring of a production work force, establishing facilities, and liaison with the Mexican federal and

state governments, and will generally shorten the implementation process.

Training. Maquiladoras in other industries have had much success in training new workers in Mexico. There has been an ample supply of workers with some training for the skills needed for shipyard work. The oil industry in Mexico has provided initial training for many of the welders and machinists. The length of time to train and certify a new welder is equivalent to the times experienced in U.S. shipyards. The productivity of the trained workers will depend on the quality of the shop equipment. Companies with maquiladoras have found that the productivity of the Mexican shops will be equal to their U.S. counterparts if the shops are equally equipped.

The cost of training will probably increase for a shipyard due to the requirement to duplicate training equipment and personnel. Most maquiladoras have found it necessary to have a training team on site in Mexico. The cost of certifying welders is comparable to the costs in the U.S. There are few welding certification labs in Mexico and the certification of test pieces will still have to be done in a U.S. lab or the shipyard.

Quality Assurance. Non-destructive Testing (NDT) can currently only be done with U.S. certified companies. Mexico does not have similar certified companies. The shipyards will have their own NDT shops to conduct the necessary inspections of welds and other regulatory requirements. Most sizable maquiladora operations will have their own NDT facilities for required tests and inspections.

The shipyard's quality assurance team will have to be increased to handle the work at the maquiladora. Test plans and schedules will require additional management attention to incorporate additional inspections at the maquiladora.

Additional coordination may also be required to schedule inspections from government inspectors and regulatory agencies. U.S. government inspectors have been regularly crossing the border to inspect the work being done on some U.S. government contracts. In other situations the completed components are first delivered to a receiving area in the U.S. where the government inspector completes the necessary inspections before delivery to the shipyard. It has been common that the government inspectors have initially been doubtful of the quality of work coming from Mexico, but they have generally found good workmanship from the maquiladora.

Classification societies are well represented in Mexico. Although there

will be a resident surveyor in the shipyard, the classification society will probably rely on their Mexican representative for any surveys of the work at the maquiladora. This will usually require that the shipyard pay for a surveyor in the shipyard as well as a surveyor at the maquiladora.

Environmental Compliance. New Mexican laws have been developed over the past 10 years. They include substantial penalties, including criminal sanctions for violators. Under the new statute that went into effect in 1989, generators of hazardous waste must comply with the reporting and disposal requirements and technical standards that have been centralized in the federal government through the Secretaria de Desarrollo Urbano Y Ecologia or (Ministry of Urban Development and Ecology) SEDUE.

Maquiladoras that generate hazardous waste must register with the government. The maquiladora must meet the requirements and maintain records related to the handling, labeling, storing, transporting, and disposing of hazardous materials. The Mexican laws closely follow the U.S. laws and in some cases as with the classification of hazardous waste they are more inclusive. It is anticipated that state and local authorities will also pass their own regulations. Since SEDUE is a new agency, the full impact of the laws and how much self regulation a maquiladora will be allowed remains to be determined.

The definition of "residue" under Mexican environmental laws could become an important cost consideration for a shipyard. It is generally defined as hazardous by-products of the maquiladora production and manufacturing process. The generator must determine if it is hazardous. The Mexican environmental laws require that the residue be returned to the origin of the original materials. Additional documentation and customs forms are required. The requirements for transporting and disposal in Mexico are similar to those in the United States. Transportation of hazardous waste from the maquiladora back to the U.S. may require a duplicate set of documents, one for Mexican requirements and one for the U.S. The worst case situation would be if hazardous materials are first picked up by a Mexican trucking company and the disposal site is not in the border commercial zone, the hazardous waste has to be transferred to U.S. trucks at the border with all the proper waste handling requirements in place.

Production Sequence. How would a shipyard utilize a maquiladora operation? The first step is to look at the overall production sequence for the construction of the ship. What parts of that procedure are the most labor intensive? Which of those labor intensive portions could be

done off-site? For example, the fabrication of the hull and superstructure, the installation of the distributive systems and the installation and alignment of major machinery are all labor intensive. However, the alignment of machinery usually can only be done after the ship is assembled on the ways or in the water. On the other hand, with the proper planning, the pre-outfitting of distributive systems and the assembly or prefabrication of structural subassemblies could be done off-yard.

The next step will require engineering to establish the maximum sizes that will be fabricated by a maquiladora. The size will be restricted by:

- . The lifting capacities at the maquiladora and the shipyard:
- . The means of transporting the completed assembly. If by water, the weight will probably be limited by the lifting capacity restriction. If by land (road or rail) then the weight will probably be restricted by state load carrying regulations;
- . Volume of the assembly will be restricted by road or rail clearances. If water transportation is used volume restrictions are not as critical: and
- . The assembly sequence for the ship. Although this may not be a physical restriction, additional engineering will be required to restructure the production sequences from previous work that was done entirely in the shipyard.

Scheduling completed assemblies from the maquiladora will be one of the biggest tasks to consider. With additional handling requirements imposed on the construction sequence, there is a greater chance of delay due to the maquiladora operation. Existing maquiladora operations even on a small scale experience their greatest problems with delays related to the transportation of completed goods to the shipyard. The processes of releasing the goods from the maquiladora plant, loading them on to a truck in Mexico, passing through customs at the border and coordinating transportation to the shipyard and finally off-loading the goods in the shipyard can cause the accumulation of many small delays that can significantly disrupt the overall production sequence.

HOW MUCH CAN BE SAVED?

Anticipated Cost Savings

A maquiladora for a U.S. shipbuilder offers a means to reduce the high cost of shipbuilding and increase the capacity of a U.S. shipyard. At the

TABLE V
Comparison of Cost Structures

COST GROUP	CONTENT MULTIPLIER	UNITED STATES	US with MAQUILA	JAPAN	NORTHERN EUROPE
Labor	0.24	1.0	0.78	0.69	1.24
Material	0.40	1.0	1.00	0.85	0.90
Overhead	0.36	1.0	1.00	0.70	0.85
Total Cost	1.00	1.0	0.95	0.75	0.96

current wage levels (Figure 1), establishing a maquiladora may not lower the cost of a U.S. ship enough to compete with the Korean shipyards, but it will make it more competitive with the Japanese and European shipyards. Although the labor rate in a maquiladora is as little as 10% of the U.S. wages, that difference does not translate directly to the overall cost of the ship. The cost of direct labor for a new ship can represent 25% to 35% of the total cost (9). The portion of the labor that could be done in a maquiladora could be as much as 50% of the total labor effort. It seems unlikely that a newly established maquiladora could provide 50% of the manhours in the total construction of the ship, however, with the proper training and production planning, that amount is not infeasible. Assuming that a maquiladora would be initially established to fabricate and assemble structural blocks, it could be expected that 20% to 30% of the total labor would be accomplished at the lower labor rates. Thus, if just the direct labor costs are considered and 25% of the total labor is accomplished at a 90% reduction in labor rates, the labor cost savings would be 22.5%. For a ship

construction project where the direct labor without a maquiladora represents 30% of the total cost to build the vessel, the 22.5% savings for direct labor translates to a 5.3% savings in the total cost. While the addition of non-labor costs related to a maquiladora operation will reduce this overall savings, the large savings in direct labor will continue to dominate.

In their 1989 SNAME paper, Carson and Lamb introduced a cost comparison table that shows the relationship of the costs to build ships in Japan and Europe to those built in the United States (1). Table V adds a column to the cost comparison to show how the introduction of maquiladora may change the cost comparison factor. The maquiladora column assumes that the cost ratios for material and overhead for the U.S. shipyards remain constant and only the labor multiplier changes. The above example using only direct labor costs established a labor multiplier of 0.78 instead of 1.0 for a shipyard without a maquiladora. This analysis shows that on a comparison with Japanese and European shipbuilders, the introduction of a

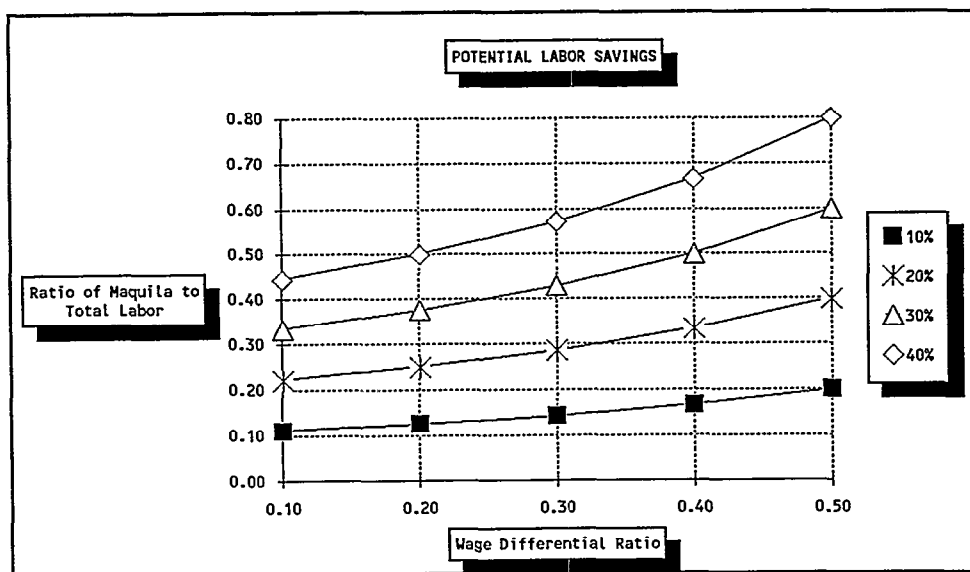


FIGURE 3
Potential Labor Savings

maquiladora can offer approximately an overall 5% cost improvement.

This first look at the potential cost savings has only considered direct labor costs because of the large number of variables that must be considered for the full analysis. Earlier sections reviewed a number of other significant start-up and operating costs associated with a maquiladora. Most of these can not be quantified until the specifics of a maquiladora operation are established. The costs will vary with the size and location of the maquiladora plant, the location of the parent shipyard, the methods and routes of transportation between the shipyard and the maquiladora, and the organizational relationship between the maquiladora and the parent shipyard.

These cost factors can be grouped into three key elements that affect the cost savings analysis of a maquiladora for any shipyard.

- .Known wage differentials between the U.S. and Mexico.
- .The amount of the total labor that is accomplished at the maquiladora.
- .The additional direct and indirect costs of operating a maquiladora plant that offset the lower labor costs.

The dependency of the shipyard's cost savings on these elements is presented graphically in Figure 3. The lines on the graph represent four arbitrary percentages of savings. By selecting a wage differential ratio on the horizontal axis and projecting up to the selected percentage savings line, the maquiladora to total labor ratio can be read from the vertical axis. The equation for each of the savings lines is:

$$S = P(1 - L)$$

where;

- P = Ratio of Maquiladora labor to the total labor.
- L = Ratio of Maquiladora wage rate to the U.S. labor rate.
- S = Cost Savings of using a maquiladora. (expressed in %)

A Case Study

Since these ratios will be different for each shipyard and probably for each type of ship constructed, Figure 3 offers a means of projecting the potential savings of using a maquiladora. To illustrate, consider a shipyard located in Southern California that has established a maquiladora in the Tijuana area. The following assumptions are used.

- The maquiladora is a fully owned subsidiary of the shipyard.
- The start-up and financing costs are amortized and included in the shipyard's overhead.
- The maquiladora is located in the free trade zone and the shipyard is located less than 25 miles from the border.
- The shipyard utilizes its own trucks and drivers.
- The shipyard has a steady workload building product carriers (approximately 40,000 dwt).
- The maquiladora is used to fabricate structural blocks for the hull of 20 tons or less.
- The shipyard burdened labor rate is five times (L= .2) the average burdened rate of maquiladora.
- Thirty percent of the total labor will be done by the maquiladora (P = 0.3).

With the maquiladora already in operation, an overhead rate will have been established. Current operations in the Tijuana area have an overhead rate of about 200% of the direct labor rate. The elements of the maquila burdened labor rate are listed in Table VI. The maquila burdened rate factor for this example is 3.0 (i.e. if the average direct labor rate is \$2.00/hr then the maquila burdened rate is \$6.00/hr).

The maquila burdened rate must be adjusted to account for the additional costs of operating the maquiladora. These additional costs are converted to a element of the maquiladora overhead cost. They are valued as fractions of the direct labor cost for the maquiladora and are assumed to be constant over the period of steady workload (multi-ship contract). As each additional cost element is added to the maquiladora burdened labor rate, the value of the wage differential ratio increases. Table VI also lists the additional cost elements and their estimated fractional value to the maquiladora direct labor rate.

The total burdened rate factor for this example is 3.88 (i.e. if the direct labor rate is \$2.00, then the new burdened rate equals \$7.76). The additional cost factors have increased the burdened labor rate by 88% of the direct labor rate. The new wage differential ratio is increased in direct proportion to the increase of the burdened rate factor.

TABLE VI
SUMMARY OF MAQUILADORA OVERHEAD COSTS
For Case Study

Cost Item	cost Factor	Remarks
Maquila Direct Labor	1.00	Base for cost factors
Maquila Overhead	2.00	<p style="text-align: center;">*** NOTE ***</p> <p>All normal overhead costs for the maquiladora operation are combined as one factor of the Direct Labor. The factor is representative of the actual overhead costs of a current maquiladora providing services for shipyards.</p>
Indirect Labor		
Vacations & Holidays		
Lease/Rent		
Utilities		
Plant Maintenance		
Vehicles		
Taxes		
Housing Fund		
Bonuses		
Maquila Burdened Rate Factor	3.00	
Additional Overhead Costs		
Customs	0.04	
Tariffs	0.00	
Bonding	0.00	
Transportation & Handling	0.36	
Management	0.05	
Training	0.15	
Quality Assurance	0.15	
Classification Society	0.03	
Engineering	0.10	
Add'l costs Rate Factor	0.88	
TOTAL BURDENED RATE FACTOR	3.88	

Original Wage Differential
Ratio: $L = 0.2$

New Wage Differential
Ratio: $L = 0.2 \times \frac{3.88}{3.00}$

or $L = 0.26$

Before the additional cost elements were entered;

- the shipyard could achieve a 24% savings in labor costs (for a wage differential ratio equal to 0.2 and maquila to total labor ratio equal to 0.3).

With the additional costs;

- the new wage differential ratio is 0.26 which reduces the labor cost savings to 22% for the same maquila to total labor ratio.

If this example ship construction program has the same relationship among labor, material and overhead as Shown in Table V, Content Multipliers, the 22% savings in labor could result in a 5% savings for the contract.

The example has demonstrated an effective approach to evaluating the

savings that can be expected from a maquiladora operation. By converting each of the start-up and operating cost to an overhead factor, their individual affect on the savings can be analyzed. If in the above example, the transportation and handling costs are doubled so that the cost factor equals 0.72 of the direct labor rate, the new wage differential ratio equals 0.28. The labor savings would be reduced by 0.04% to 21.6% for this change in operating cost. Each of the other cost factors can be analyzed in a similar manner.

CONCLUSIONS

Maquiladora Operation Can Reduce Labor costs

Maquiladoras have proven that they can reduce labor costs enough to allow many U.S. companies to remain competitive globally. They have become an integral part of U.S. manufacturing. Even when all maquiladora operating costs are added to the direct labor costs the fully burdened labor rates for a maquiladora can be expected to be less than one third of the U.S. shipyard labor rates. Labor cost savings of 25% should be achievable for most U.S. shipyards.

Effective Maquiladora Management Necessary to Achieve Savings

The establishment of a maquiladora will not in itself improve the productivity of the shipyard. In fact, it could adversely affect a shipbuilding program if it is not properly integrated into the production schedule. However, U.S. shipbuilders have often successfully incorporated major subcontractors and even other shipyards into a new construction program. Utilizing the same effective planning and management, the introduction of a maquiladora operation will enhance the current productivity and provide additional flexibility to improve the overall shipyard efficiency.

Maquiladora Operations Can Increase Capacity

The capacity of an existing shipyard should be increased with the use of a maquiladora. The maquila should open new areas in the shipyard previously used for prefabrication and block assembly. The new areas will provide an opportunity to improve yard efficiency by establishing better material flow patterns. Using a maquiladora may open up enough real estate to consider an additional outfitting pier, graving dock or building ways. In any case, the relocation of the work planned for the maquiladora should allow the shipyard greater flexibility with its valuable waterfront property. If the goals of the long range strategy are achieved, the increased capacity will be necessary to accommodate the increased workload.

Maquiladora Can Open New Markets

The combination of reduced labor costs, enhanced productivity, and increased capacity will allow the shipbuilder to increase market share. These steps to increased market share are not sequential, but must be planned and executed in parallel. The maquila won't be effective unless it is carefully integrated into the overall production plan. Likewise, the new opportunities for increasing capacity must also be a part of that overall plan. The consequence will be significantly lower costs for labor and an opportunity to be price

competitive with Japanese and European shipyards. The starting point is a redefinition of the shipyard's long range strategy to include the establishment of a maquiladora.

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Composite Materials and Naval Surface Combatants: The Integrated Technology Deckhouse Project

IIIB-1

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ABSTRACT

Composite materials, particularly fiberglass, have created a revolution in commercial marine design and construction over the past 20-30 years. The U.S. Navy, however, has been slow in recognizing the value of composite materials and implementing their use. The current construction of a fiberglass minesweeper will introduce composites into the auxiliary Navy, but major surface combatants have yet to take advantage of their unique material properties.

The Integrated Technology Deckhouse (ITD) Project has been steadily progressing toward the goal of constructing Naval combatant deckhouses out of an integrated system of steel and composites. The approach of the ITD Project has resolved problems and issues in phases, with each phase becoming progressively narrower in scope and greater in detail. The first phase of the project was primarily a materials and structural concepts trade-off study. Material properties were reviewed for a variety of fiberglass composites and design concepts, resulting in a trade-off matrix. The second phase included a shipyard producibility study. Issues associated with working with composites in a modular, steel construction environment were addressed. Recommendations from this study were then addressed in detail in a follow-on producibility study.

In the most recently completed study, the producibility issues associated with the design and construction of the DDG-51 Class forward Close In Weapons System (CIWS) maintenance enclosure were addressed. This paper reviews the progress to date in the ITD project, highlighting the significant issues and explaining why some of the major decisions were made. Emphasis is placed on the most recent phase of the project, which concentrated on a specific ship unit.

INTRODUCTION

The continuing efforts of the U.S. Navy to reduce weight and increase survivability of Naval combatants has led to the serious development of composite technology for use on combatant ships. Composites, especially fiberglass, have revolutionized design and construction in the commercial marine industry. Until recently the impact has been primarily on pleasure craft and other small boats. Technological ad-

vances in materials and construction processes have led to larger composite boat designs as well as an increased interest in the use of composites by the U.S. Navy.

Although large combatant hulls will most likely continue to be constructed of steel, polymer composites may be integrated with more traditional ship building materials to form hybrid structures. Because of their high strength to weight ratios, composites are particularly attractive for weight critical areas. In the past, aluminum has been used to keep weights and centers of gravity down, but has proven to be a less than ideal material for combatant deckhouses. In the future, polymer composites may be the material of choice for deckhouse structures. The U.S. Navy's Integrated Technology Deckhouse Project is steadily progressing toward making this a reality.

BACKGROUND

The objective of the Integrated Technology Deckhouse (ITD) Project is to enhance the survivability of U.S. Navy combatant surface ships. Composite materials have been chosen as a means to achieve this enhanced survivability because of several factors. Composites allow an integration of a number of survivability requirements, have beneficial material characteristics and may reduce maintenance requirements. One of the major advantages over steel or aluminum is in fire containment. Although composites will burn at high temperatures, the thermal conductivity is considerably less than metals. A fire occurring in a composite space will not transmit significant heat through the bulkheads to adjacent spaces. Spontaneous combustion in spaces adjacent to the fire, such as that experienced on the U.S.S. Stark, should be prevented.

Polymer composites also have excellent ballistic properties, yet are considerably lighter than equivalent steel armor plate. Reduction of topside weight, although not yet an issue on the newest Navy destroyers, is an additional advantage of composite deckhouses. Because of their high strength to weight ratios, composite materials can result in a 25%-30% reduction in structural weight. Finally, properly prepared composite materials are nearly impervious to the corrosive effects of the ocean environment, resulting in reduced maintenance.

The ITD Project has been on-going since 1987, with sponsorship by Operational Navy (OPNAV) Code 03C2,

program management by Naval Sea Systems Command (SEA) Code 5112 and technical management and coordination by SEA55Y. David Taylor Research Center in Carderock and Annapolis, Maryland has played a key role in resolving technical problems. The Navy has used a design agent as prime contractor to complete much of the design and engineering work and to subcontract work out to shipyards and composite manufacturers. Additionally, there has been active participation since the inception of the project by three major surface combatant construction shipyards. The early involvement of the shipyards has been extremely valuable in ensuring that technical concepts developed in the labs and by the design firm can actually be built in a shipyard.

The project has been established as a three phase effort. Phase A, from FY87 to 1st quarter FY89, was a concept development and material characterization stage. Phase B, dedicated to technical development and validation of design details and structural elements, is scheduled through FY91. During this phase the efforts of the project were, and continue to be, focused on the construction of a Close In Weapons System (CIWS) maintenance enclosure for DDG51 Class destroyers. Phase C, scheduled for FY92-FY94, is planned to be the full scale deckhouse unit fabrication, erection and evaluation.

The project is currently on schedule and well into Phase B. The CIWS structural design is nearly complete, and the testing of design details will occur during the summer of 1991.

PHASE A

Phase A consisted of a number of paper studies and small scale testing. The paper studies included identification of technology areas and definition of design criteria. Phase A culminated in an *overall* Material Systems and Structural Concepts Trade-off Study. A number of different material systems were considered for use in the ITD Project. Five major factors were used as evaluation criteria in deciding which material was best suited for the project. These factors were:

- specific strength
- fire resistance
- environmental suitability
- fragmentation protection
- acquisition cost and availability

Using these evaluation criteria a fiberglass composite made from a woven roving E-glass solid laminate vinylester resin system was chosen as the primary material. The additional strength characteristics of a 70% glass (70% glass to resin weight ratio) system made it the primary choice for exterior and structural bulkheads, while a 50% system was recommended for non-structural and joiner bulkheads.

The second part of the study evaluated a number of different structural concepts for composite deckhouse construction. Molded construction and modular construction using a framework and panels were both considered, with modular construction chosen for the project. Modular con-

struction eliminates the need for molds, does not require extensive facility upgrades by shipyards building primarily steel combatants, incorporates construction techniques familiar to most shipyards and may reduce the risk and costs associated with repairs and rework. Composite panels are also easier to ship from the fabrication facility to the shipyard than large molded structures.

Once this decision was made a number of new issues arose, including composite versus steel framework, single bay versus multi bay panels, integral versus non-integral stiffeners and adhesive versus mechanical fastening. Candidates were evaluated using the following criteria:

- structural weight
- ballistic performance
- fire containment
- electromagnetic properties
- producibility, repairability and maintainability

At this stage of the program a matrix of concepts and their advantages and disadvantages was developed rather than selecting a specific concept, as the optimum structural concept will be dependent on the actual deckhouse configuration.

PHASE B

Phase B of the ITD Project concentrated initially on solving the air blast and fire issues, as well as continued shipyard support. A simulated nuclear air blast test was performed on a small (2.44m (8') by 2.44m (8') by 4.88m (16')) composite module. In addition, a series of fire tests, including a large scale "Stark" fire simulation, were conducted on a similar sized module. The results of these tests supported the choice of materials.

An in depth shipyard producibility study was also conducted during this phase. The study identified and resolved producibility issues associated with the design and construction of a generic composite deckhouse structure. Significant contributions were made to the ITD Project in the areas of fabrication, safety and non-destructive testing and evaluation techniques. Methods of construction were reviewed and several alternatives identified for most production tasks.

The study made a number of recommendations pertaining to panel fabrication and storage. Composite panels will be manufactured by a vendor contracted through the shipyard, as the yards currently involved in major naval combatant construction have limited capability for large scale fiberglass panel fabrication. The shipyard or design agent will provide the manufacturer with the necessary design information to fabricate either custom or standard panels. Gel-coat will be applied by the panel manufacturer to prevent environmental damage to the panels during construction. Panels must be carefully handled and stored, preferably in a vertical racking system.

The design of the deckhouse panels should minimize the requirement for cutting and trimming of the panels by the

shipyard. This will reduce construction time and cost by eliminating some of the Occupational Safety and Health Administration (OSHA) requirements and safety measures that must be taken when working with fiberglass. Manual methods were evaluated and will be used where cutting is necessary, eliminating the need for shipyards to invest in automated fiberglass panel line equipment. Panel fastening will be accomplished with a combination of adhesives and mechanical fasteners. Although sole use of adhesives and fiberglass bonding methods is more appealing for both strength and reduction of topside clutter, the difficulty in integrating steel and composites and the requirement for controlled conditions for fiberglass layup mandates the use of bolts at panel joints and attachment points. The use of steel transition pieces (similar to the bimetallic strips used on aluminum deckhouses) and welding near panels was ruled out by the study due to potential damage from the weld heat.

CIWS MAINTENANCE ENCLOSURE

During the latter part of Phase B, the forward CIWS maintenance enclosure of the DDG-51 Class destroyer was chosen as the first actual ship's structure to be constructed under the project. The CIWS enclosure was chosen for several reasons. Its size approximates that of the air blast and fire test modules, allowing the use of experimental data in the development of the unit design. It was anticipated that the deck and bulkhead connections could be easily accomplished as it is a relatively small unit with straight edges. Changing the CIWS enclosure structure will also have minimal impact on the overall ship design and construction due to its isolated location and small level of outfitting. It should be noted that the Vulcan Phalanx CIWS gun mount foundation is actually on the structural unit below the maintenance enclosure, so that the issues associated with mounting large, heavy items on a composite deck are not addressed. The unit will be used to test key issues such as EMX, fire protection, producibility, shock and fatigue. Finally, the design can be incorporated as either a forward or back fit into both the DDG-51 Class destroyers

and aircraft carriers. Figures 1 and 2 show the relative location and configuration of the enclosure.

The decision to construct a CIWS enclosure led to an additional producibility study by the lead shipbuilder of the DDG-51 Class, as well as the development of detailed test plans and schedules for implementation of the project.

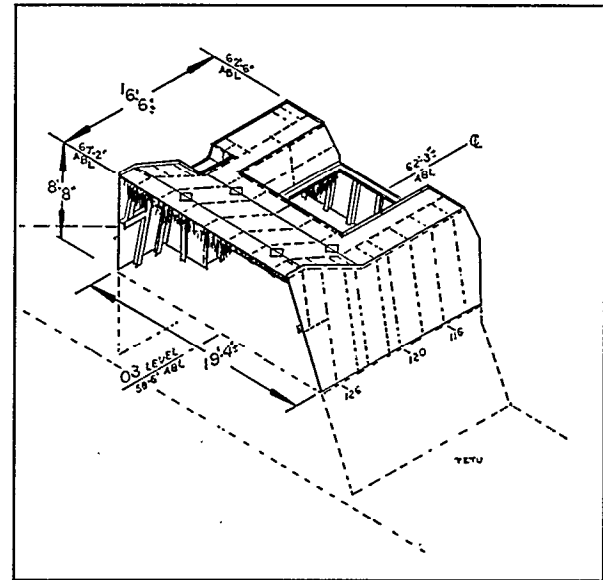


Figure 2

PRELIMINARY DESIGN DATA

Prior to tasking the producibility study of the CIWS enclosure, the structural concepts to be used were chosen from those identified in the previous studies. Preliminary structural drawings were developed by the design agent and provided as a baseline for the CIWS producibility study. The unusual geometry of the enclosure dictates the use of large custom built panels rather than standard size panels. These panels will be

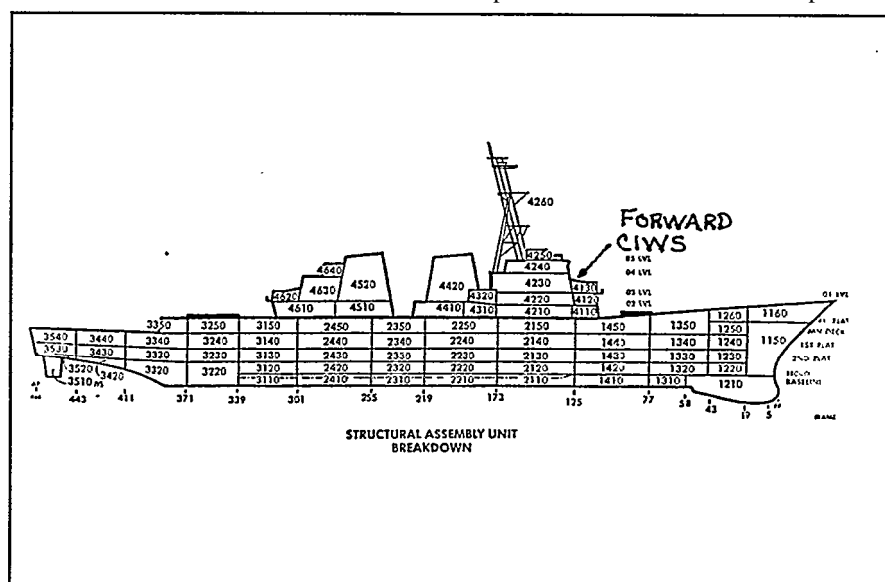


Figure 1

fabricated using the 70% E-glass/vinylester resins in system. The initial design called for one half inch solid laminate panels, thickening to three-quarters inch at the edges to provide a stronger faying surface. The design had foam or balsa cored hat stiffeners integrated into the panels during layup, a steel framework consisting of angles at the joints, and a steel flat bar at the deck and bulkhead connections. The angles were connected to the panels using steel bolts and the edges sealed with the same vinylester resin used in the panel fabrication.

It was anticipated that the assembled unit will be temporarily erected on the ship, and the deck and bulkhead edge locations scribed onto the adjoining units. The enclosure will then be removed and the flatbar (with pre-drilled bolt holes) welded in place and straightened as necessary. The fully assembled enclosure is then lifted back onto the ship and bolted in place, applying a resin sealer to the joints. This preliminary construction method was later modified during the shipyard study.

A small number of outfitting details, based primarily on techniques developed during design of the MHC-51 Class Coastal Minehunters, were also provided with the preliminary design. These included methods for installing pipe and vent hangers, electrical cableways and foundations.

CONSTRUCTION PHILOSOPHY

Previous studies recommended the continued use of modern modular construction and zone outfitting methods currently in use in many shipyards. The CIWS study concurred with the recommendations and identified construction approaches that will result in as little deviation as possible from present shipbuilding practices.

STORAGE AND HANDLING

One of the initial steps in the construction process is the receipt and storage of construction materials. The expense and long lead times associated with composite panels requires a more careful process than that used with steel plate. To prevent environmental damage prior to erection on the ship the panels should be stored inside. A vertical racking system is the preferred method of storage, particularly for custom panels, as the panels will only have to be moved once during each construction phase. Each panel will also be readily accessible when needed.

Several methods of handling the composite panels were recommended by the various shipyard studies. The use of vacuum cups appears to be the best method as no modifications to the panels are required. Other methods include the use of slings, which is labor intensive; holes drilled in the panels, which will require later rework; and laminated fiberglass padeyes. An advantage of laminated padeyes is that, if properly designed and located, they may be left in place and used for unit lifting and erection of temporary scaffolding.

PANEL DESIGN

The next step to consider was the design of the panels

themselves. Earlier studies had considered both custom made and standard panels, with custom panels as the final recommendation. For a DDG-51 Class deckhouse this is the only logical choice due to its unusual configuration and varied geometry, as shown in Figure 3.

The use of standardization during custom panel design and fabrication should, however, result in lower shipbuilding costs. Maintaining a degree of consistency between panels allows the shipbuilder to fabricate connection and mounting parts on a large scale, rather than designing and fabricating completely unique pieces for each panel. It also allows the tradesmen to develop a familiarity with the product, which eventually results in reduced production manhours. Stiffener spacings and dimensions, panel thicknesses and faying surface widths are some of the items that, if held to a strict standard, will reduce overall costs.

An additional consideration is the amount of pre-outfitting to be accomplished by the panel vendor. By working with the shipyards on a jointly developed design the panel manufacturers should be able to fabricate panels that incorporate a number of attachment points for outfit items, resulting in a shorter production cycle in the shipyard and fewer opportunities to damage the panels during the production process. The disadvantage to this is the possibility of improperly located attachment points resulting in rework and delays. Strict quality assurance procedures and accurate, fixed designs will prevent this problem.

FRAME DESIGN

The next major design consideration was the type of framing system to use. It was decided relatively early in the ITD project to use a steel or composite frame system to hold the panels together. Several factors must be considered in the design of a framing system. It must be adaptable to several types of composite joints, all of which will be addressed by the CIWS maintenance enclosure. These include:

- GRP deck to GRP bulkhead
- GRP deck to steel bulkhead
- GRP bulkhead to steel bulkhead
- GRP bulkhead to steel deck

Panels and their connections must be designed for nuclear air blast loading, meeting strict requirements for panel deflection, sheer and bending moments. The framing system should minimize weight, but not at the expense of producibility. Finally, the unique configuration of the DDG-51 deckhouse units will require the use of non-standard shapes.

Two types of framing systems were considered as candidates for the CIWS enclosure. Each has its merits and its disadvantages. The first type, with framing members located only at the panel edges, is shown in Figure 4.

The panels are bolted to the frame members and act together to provide the structural strength and stiffness of the unit. This type of framing system will allow the use of composite framing members and offers the minimum structural weight. Construction using this framing method will

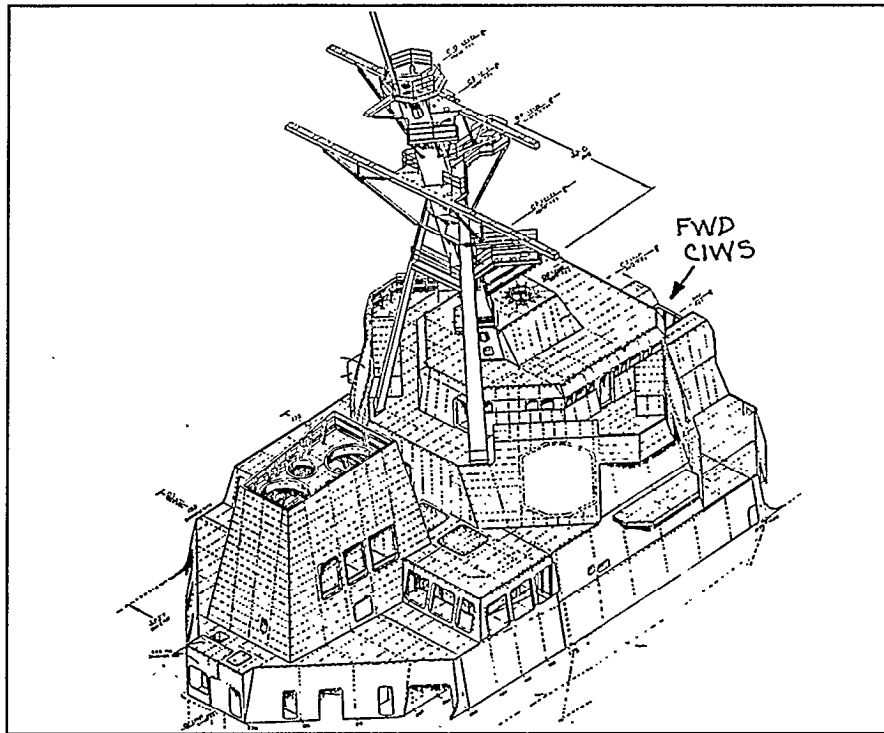


Figure 3

require the panels to be erected one at a time, bolting them to the frame pieces in sequence while supporting the partially finished structure with a mock or jig.

The other option considered for a framing system was a free standing structural frame constructed of steel. The framework is welded together and has some inherent structural strength prior to bolting the panels onto the frame. This method is obviously heavier, but provides additional points for joining to ship's structure and attaching distributed systems. It may also help support distributed systems in the event of catastrophic fire damage. This type of frame is shown in

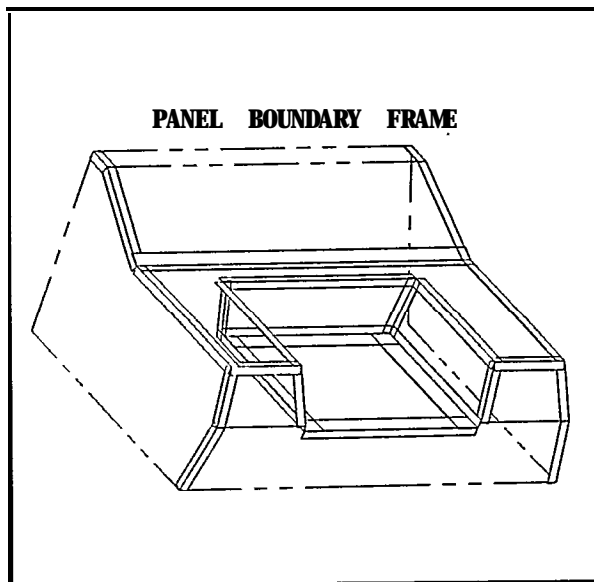


Figure 4

Figure 5. The final choice for the project is a combination of the two systems; a steel panel boundary frame with some additional steel members at critical points.

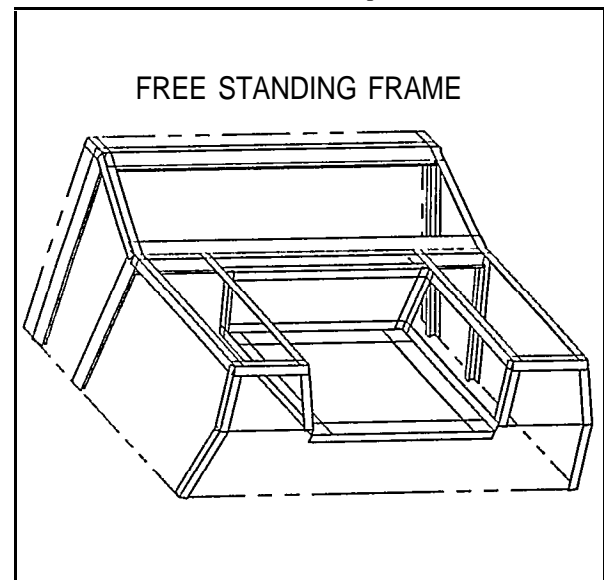


Figure 5

JOINT DESIGN

One of the greatest challenges during this study was to develop a method of connecting the composite panels to steel plate bulkheads and decks. The connection must be air and water tight and able to meet all compartment test requirements. It must be resistant to corrosion, cracking and pitting. It must also be lightweight and producible. Various connection methods were considered, including mechanical fasten-

ing, adhesives and welding, as well as combinations of the aforementioned. The early ITD studies considered steel plates embedded in the edges of the panels and then welded to the adjacent deck or bulkhead. This was ruled out because it was assumed that the high heat from welding would cause significant damage to the composite panels.

The suggested method was to weld the steel coaming to the adjacent structure and then bolt the composite panels to the coaming. The problem with this method is that difficulties in obtaining alignment within tolerances are anticipated when erecting the assembled composite unit onto the ship. An alternative method that will prevent alignment problems by allowing welding near the panels needed to be developed.

The CIWS study proposed that the transition pieces be temporarily bolted to the panels until the unit is erected and supported by temporary jacking stools. Once proper alignment is obtained the transition pieces will be welded to the adjacent steel plate and the permanent bolts installed and torqued down. This method still left the heat damage issue open.

In order to verify the practicality of the proposed construction method a welding heat experiment was conducted. Steel flatbars of varying thickness and width were welded into a tee shape with temperature probes attached to the vertical member of the tee as shown in Figure 6.

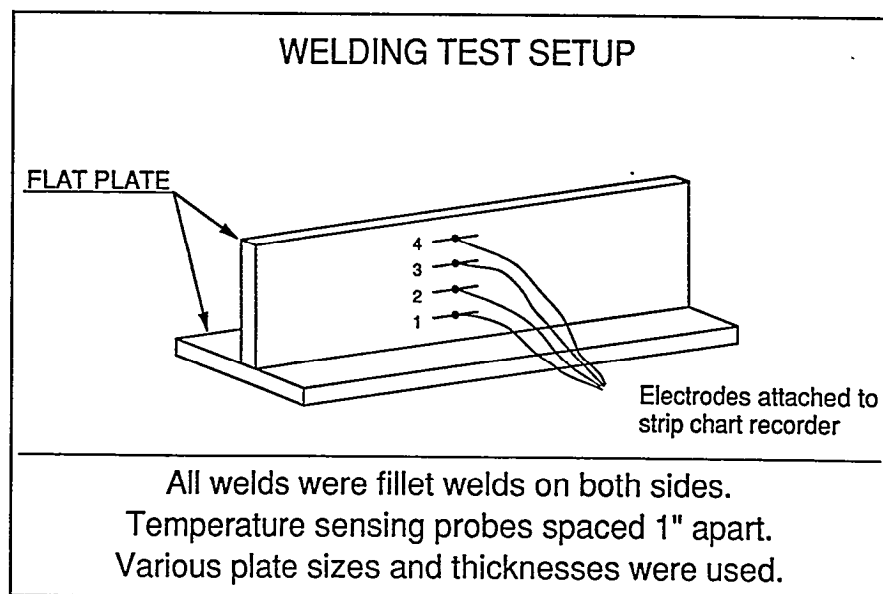


Figure 6

Two different types of welders were used; a pulse gas metal arc welder and a flux core welder, which is the hotter of the two. Single and double passes were conducted, as well as several with a preheat to simulate summer conditions. The temperature of the plate was measured at one inch increments from the weld and recorded on a strip chart recorder for the duration of the weld.

The critical temperatures for the E-glass/vinylester resin panels are shown in Table I.

Table II shows the test results. The results of this test demonstrate that depending on the type of plate used it may be possible to weld as close as one inch to the composite panels without significant damage, validating the proposed construction method. Several types of connections using this method were designed, with the preferred option shown in Figure 7.

OUTFIT DESIGN

Outfitting methods to be employed are another major challenge of the project. Outfitting includes the installation of all piping and mechanical equipment, combat systems and equipment, electrical equipment and cableways, ventilation ductwork and hull outfit items such as doors, ladders, gratings and habitability components. A steel or aluminum deckhouse is typically outfitted by welding foundations or hangers onto the structure and attaching the system or outfit items to them. Obviously this cannot be done with a composite structure. In most cases the existing hanger designs can be used, but the method of attaching them to structure will be modified. A number of possible methods were developed as part of the CIWS study, including attachment with adhesives, laminated attachment points, through bolts on stiffeners and bolting through the panels. Tap screws and rivenuts can also be used, provided shock requirements are met. Figures S-11 show examples of the different types of methods that were conceived during the CIWS study.

REWORK AND SHIPYARD REPAIRS

Rework during construction on a steel structure often requires cutting or burning off the incorrect component, grinding down the steel plate surface and welding a new component in place. Rework with composites may, however, result in a labor intensive sanding, patching and re-laminating process. It is anticipated that common fiberglass boat building technology will be used to accomplish any required repairs.

Nomenclature	Temperature	Effect
Glass Transition Temperature	100 deg C 212 deg F	Surface changes and resin softening. Depth of laminate exposed to 100 deg is degraded.
Thermal Degradation	200 deg C 392 deg F	Gas emission, volatiles separate without burning- Phase change starts on surface.
Thermal Decomposition	300 deg C 572 deg F	Laminate starts to char and burn. More gases released. Permanent damage results.

Table I

WELDING TEST RESULTS							
HORIZ PLATE	VERT PLATE	PEAK TEMPERATURE					
		NEAR(FAR)	NEAR(FAR)	NEAR(FAR)	NEAR(FAR)		
3/16"X8"	3/16"X4"	360(300)	210(190)	180(160)	N/A	*#	
3/16"X8"	3/16"X8"	370(365)	210(210)	165(160)	140(130)	* #	
1/2" X8"	3/16"X4"	280(265)	160 (160)	140(140)	N/A	*#	
1/2"X8"	1/2"X4"	510(460)	360 (330)	320 (300)	N/A	*+	
1/2"X8"	1/2"X8"	480(460)	330 (310)	260 (240)	210(200)	§+	
3/16"X8"	3/16"X8"	400(370)	280(260)	200(200)	185(170)	*#.	
1/2"X8"	1/2"X8"	500 (510)	360 (360)	280(280)	240(240)	§+.	
. Pulse gas metal arc welder # 1/8" fillet weld . Preheat to 200 °F, cooled § Flux Core welder + 3/8" fillet weld to 180°F prior to welding							

Table II

Since fiberglass resin layup normally requires an environment with controlled temperatures and humidity, rework will present some difficulties on the shipways, particularly during winter months. For the CIWS enclosure a temporary cover and space heaters will be adequate, but this problem must be addressed prior to construction of an entire deckhouse. The best solution is to avoid rework altogether, making it especially important to ensure that design and construction practices minimize the possibility of errors.

PAINTING AND CORROSION CONTROL

The use of an integrated system of steel and composites presents a unique challenge for corrosion control. Although the composites are not themselves susceptible to

corrosion they are not impervious to environmental damage. If not properly coated the long term effects of ultraviolet radiation will cause material degradation. Long term exposure to the ocean environment will also result in water and mineral absorption problems. A gel coat applied by the panel manufacturer will discourage these problems, but touch-up will be required by the shipyard prior to final painting.

The design used to integrate the steel and composites may also create crevice corrosion problems on the steel members. Steel erection units are normally grit blasted and primed prior to accomplishing most pre-outfitting. A steel/composite unit can not be put through the normal blasting process, so the steel framing members must be prepared separately prior to bolting to the panels. Weldable primer will

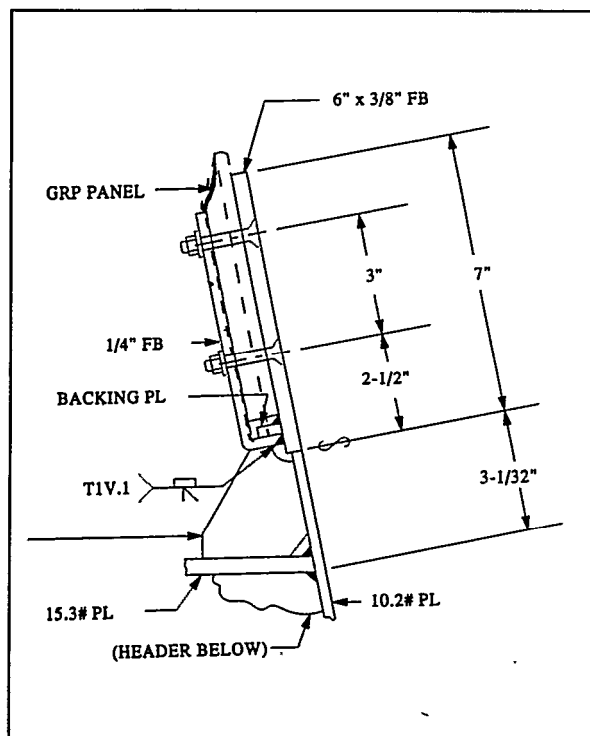


Figure 7

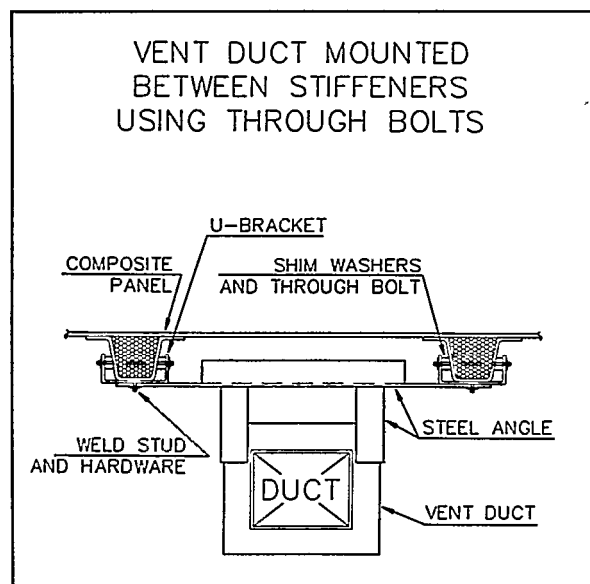


Figure 8

have to be used on most parts to allow for welding. Flexible caulking is required at the composite/steel interface to create an air and watertight seal. The seal must remain intact during normal expansion and contraction of the steel plate from ships motion and environmental heating and cooling.

Actually putting a unit to sea and exposing it to the rigors of the ocean environment will test the effectiveness of these protective measures. New inspection and underway painting procedures must be developed to counter corrosion problems that may occur.

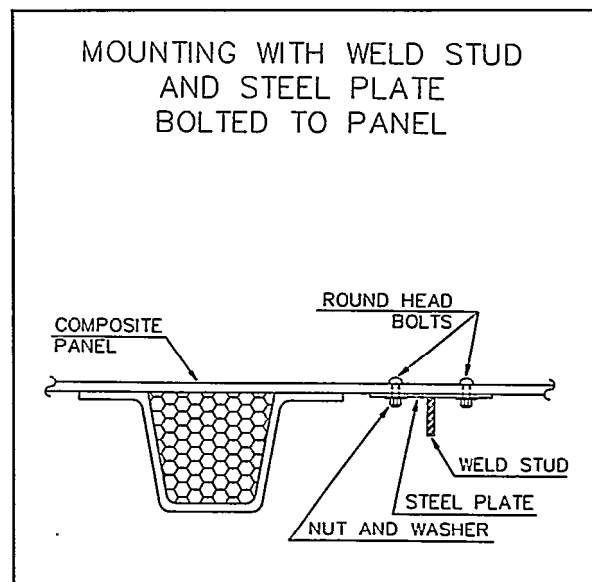


Figure 9

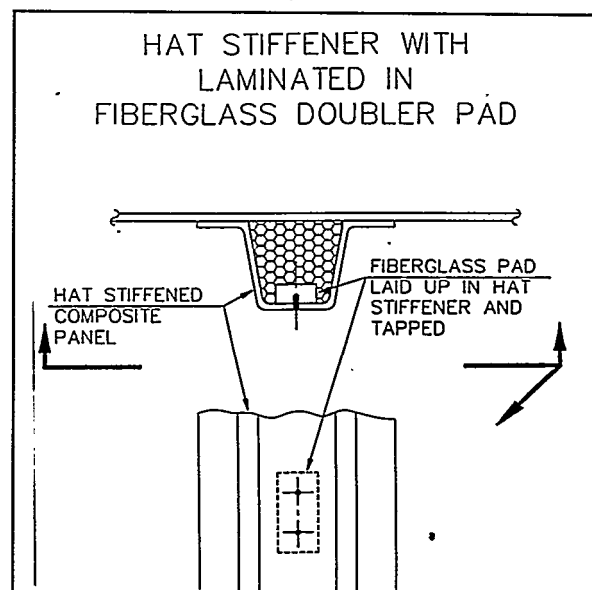


Figure 10

MAINTENANCE REQUIREMENTS

Maintenance of a composite/steel structure by ship's force will be far different than that required for an all steel or aluminum vessel. Maintenance must become more inspection oriented and conditional, fixing defects or problems as they are found rather than performing regular preventive maintenance. Training will be required to instruct crew members on how to detect damaged gel coat, blisters, delamination and corrosion at the steel/composite interface. Period checks on bolts and seals will be required and care must be taken when performing hot work in the vicinity of composites.

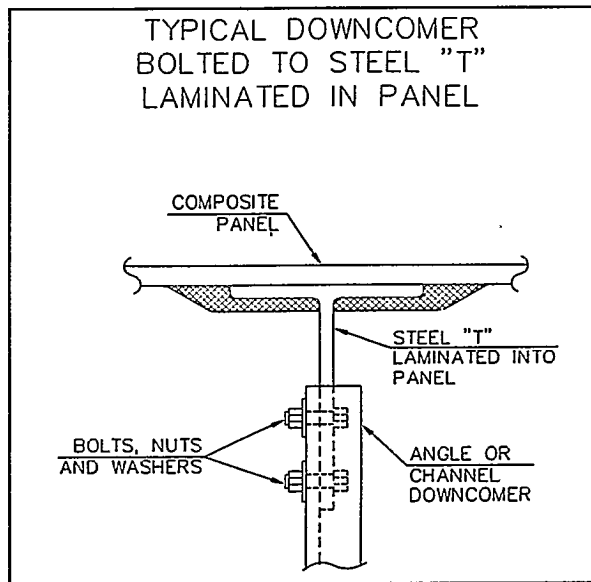


Figure 11

CONCLUSIONS

The use of composites on large naval combatants has the potential to be a cost effective means of increasing survivability and decreasing weight. The remaining milestones prior to erection of a CIWS maintenance enclosure aboard a DDG-51 class ship will continue to present challenges to those working on the project. The successful erection and subsequent trials of the unit may potentially open the door for a larger scale introduction of this technology into naval shipbuilding.

ACKNOWLEDGEMENTS

The author would like to thank Mr. Alan Kurzweil of Naval Sea Systems Command and Mr. Bill Gregory of CASDE Corp., two of the key players in the ITD Project, for their assistance in the preparation of this paper. Thanks also to Mr. Tim Tetu of BIW for the DDG 51 isometrics.



Permanent Composite Cladding of Deteriorating Steel Hulls

III8-2

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ABSTRACT

The 42.7 m (140 ft) steel steam yacht (S/Y) MEDEA was nearly condemned in 1988 because of deteriorating steel hull plate. However, it was recently restored with a structural foam and composite skin bonded to the outside of the remaining steel structure. The composite repair was completed at a cost of \$220,000 compared to the \$1.7 million estimated to crop and replace the wasted steel plate.

The repair, the events leading up to the repair, including U.S. Coast Guard approval, the structural and production decision making processes involved, and the projected use of an integrated production system for similar future applications are described in this paper. The use of similar processing technology to apply the glass epoxy composite coating on the wooden coastal minehunters (MHCs) is also discussed.

INTRODUCTION

Steel became the marine construction material of choice in the late 1800's due to its stiffness, strength and damage tolerance. Coating systems of that time were crude but, with early ships being overbuilt, excess wastage was acceptable, as were occasional leaks. Current steel construction is to a much tighter standard with very little excess plating for wastage and sophisticated coatings to preserve the relatively thin shell plating.

Composites, mostly fiberglass reinforced plastics (FRP), became common marine construction materials in the 1960's. FRP has the advantages of light weight, corrosion resistance, ease of construction, and lower cost in comparison to steel, wood and aluminum vessels in lengths of 21 m (69 ft) and less. Sandwich composites take some of the FRP advantages one step further by using relatively thin FRP skins (inner and outer layers) "sandwiching" a low density foam or balsa core to achieve adequate panel stiffness at even further reduced weights. FRP vessels have steadily grown in size to where 40 m (130 ft) yachts are common, one 49 m (160 ft) yacht is under construction, and the U.S. Navy is building 55 m (180 ft) MHCs.

The MEDEA, built of steel in 1904, falls between these two extremes of building philosophies. The vessel had been well cared for, but many years of salt water use had deteriorated much of its structure. Permanent repairs of the steel structure were beyond the financial means of its owners, but a repair that combined advantages of both steel and FRP materials was feasible and attractive from the standpoint of both an engineering and cost.

MEDEA HISTORY

Tracing the vessel's history leading up to the actual repair to the MEDEA helps put the repair into perspective. Much of this historical tracking describes working with Coast Guard authorities to achieve acceptable levels of safety for operation in U.S. waters, a procedure that is often misunderstood. More details about the vessel's full history are available from the San Diego Maritime Museum (1), the current owners of the vessel.

The MEDEA was built in England in 1904 of 6.4 mm (0.25 in.) mild steel shell plate with fairly close 500 mm (20 in.) spaced transverse frames. The vessel spent much of its life as a well cared for private yacht, with other periods in the hands of members of British Parliament and the builder's family (2). The MEDEA did service during both world wars and passed through a number of other owners. It was finally purchased and transported from Scandinavia to Whidby Island in Los Angeles for restoration in the early 1970's. It was then sailed under its own power to San Diego and donated to the Museum there in 1971. It was first certificated by the U.S. Coast Guard as a "miscellaneous" vessel under Title 46, U.S. Code of Federal Regulations (46 CFR), Part 90.05-1 (3) in 1977 because it had a steam plant operating in U.S. waters.

Coast Guard Certification

When the MEDEA was first certificated, the Coast Guard accepted a number of existing repairs to the hull plate and framing that had been performed to a standard less than normally required

by the Coast Guard. The repairs were permitted because of the vessel's limited service and because of the ample availability of rapid rescue or grounding to avert the consequences of minor flooding. These "temporary" repairs consisted of around 30 doublers, clad welding and epoxy patches to maintain the watertight integrity of the hull.

Doublers are additional plates welded over areas where the original hull plate is severely deteriorated, usually beyond 25 per cent wastage, which is the allowance built into the American Bureau of Shipping Rules for Building and Classing Steel Vessels Under 200 Feet (61 m)(4), (ABS Rules). This is normally allowed by the Coast Guard before renewals are required. It is a simpler repair than cutting out the bad plate and welding or, in the case of the MEDEA, much riveting, to make permanent repairs to the plating. Simple fillet welds and roughly fit plates are used for doublers as opposed to the careful fitting and two side welding normally required for insert plates.

Clad welding is a method of building up the steel plate thickness by overlaying numerous layers of weld metal in way of localized pitting and pinholes. This method is not widely accepted for permanent repairs because of the large welding heat input to thin plate areas causing locked in stresses, and because of the susceptibility of the overlapped welds to increased corrosion attack.

When the MEDEA was hauled out for a drydock inspection in 1986, numerous additional holes, wasted areas and loose rivets were discovered. The Coast Guard allowed 12 additional doublers and more clad welding, rivet ring welding, and epoxy patches. But a definitive plan for permanent repairs was also required or the MEDEA would have had its certificate removed.

Repair Proposals

In early 1987 the owners of the MEDEA first proposed the FRP cladding of the vessel. The Coast Guard's San Diego Marine Safety Office initial response to this proposal was that Navigation and Vessel Inspection Circular (NVIC) 7-68, Notes on Repairs to Steel Hulls (5), required repairs that were to "renew as original" the steel hull plate. The Coast Guard was slightly mistaken in stating that the NVIC "required" renewal of the steel plating as original. Because, NVIC is a Coast Guard produced document publishing recommended practice without the official public comment and legal procedure followed for regulations that are promulgated from U.S. Law, a NVIC can not be

made a requirement. Nonetheless, most marine industry people accept NVICs the same as regulation, as was the case initially for the MEDEA owners.

The Coast Guard was also going to consider the FRP cladding repair a complete alteration, but invoked the requirements of regulations in 46 CFR 92.07-10 (3), supposedly requiring the vessel to be constructed of steel or "other suitable material, having in mind the risk of fire." Even though imposing that particular regulation on a vessel the size and type of the MEDEA was beyond the applicability of that regulation, the owners of the vessel, especially considering its poor condition, had little basis for appeal.

The Coast Guard finally withdrew certification for the MEDEA in September of 1988, citing the lack of progress towards or a plan for permanent repairs. Bids were sought for making the required repairs in steel, but the estimates ranged from \$1.2 to \$1.7 million, far beyond the means of the San Diego Maritime Museum.

However, another attempt was made to obtain approval for the composite cladding repair, this time appealing the decision of the local Coast Guard office to Coast Guard Headquarter's, commercial vessel safety technical Office of Merchant Marine Safety, Security and Environmental Protection (Commandant (G-M)), Marine Technical and Hazardous Materials Division (G-MTH). The headquarters office reviewed the proposal based on its overall technical merits and the provisions for "equivalent safety," 46 CFR 90.15-1 (4). Approval was given as long as some additional conditions were met, those being to show:

1. An acceptable method for strengthening the internal structure;
2. An adequate midship section modulus with the FRP sheathing; and
3. Sufficient strength of the FRP to steel interface.

THE PERMANENT REPAIR

The basics of the FRP cladding are shown in Figure 1 (6). The MEDEA's steel hull was blasted to white metal and given a thin coat of vinyl ester resin to quickly seal the bare steel. A linear polyvinyl chloride (PVC) foam was vacuum bonded to the hull with a putty resin and faired, and three layers of woven glass fibers alternating with chopped strand mat (CSM) were bonded to the foam. Finally the FRP was faired, then painted

with epoxy primer and anti-fouling paint. The repair will be described from the structural aspect and from the aspect of producibility.

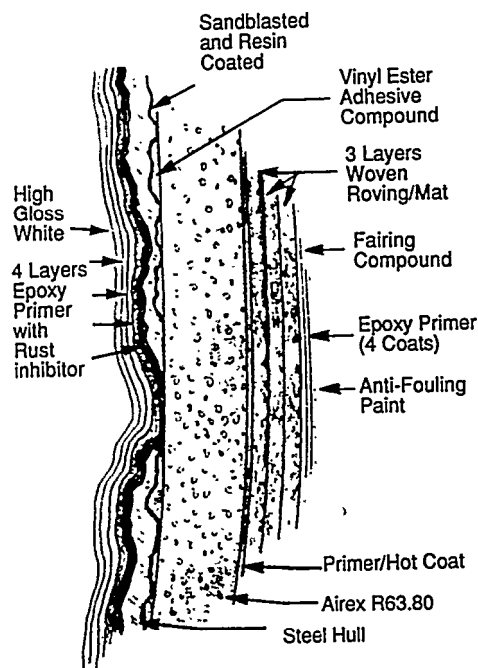


Figure 1
FRP CLADDING

Steel and Fiberglass Composite

The main structural concerns that had to be addressed for the MEDEA were local panel strength and longitudinal hull bending strength. A full description of the structural interactions between FRP and steel skins sandwiching a low density core material for panel stiffness is fairly complex and beyond the scope of this paper, so a brief analysis of the resulting structure will be given with references to works of much greater detail.

An analysis of sandwich composites attempting to adapt relationships from metals fails for two primary reasons.

1. Steel and aluminum are relatively high modulus isotropic materials with the resulting analytical equations becoming quite simplified.

2. Composites are low modulus highly orthotropic materials that respond quite differently under load, especially with even lower modulus, lower density structural cores in a sandwich structure.

The best method of analyzing sandwich composites is to treat the core as an elastic foundation as was proven by Berman et al (7) using three independent methods, each which verified the results of the others. Applying these methods to the repair of the MEDEA shell plating shows that the local panel stiffness of the FRP sandwich clad steel is renewed. The results of that analysis are shown in Table I. These results are compared to the shell plating thickness currently required by the ABS Rules.

Table I.
PANEL STIFFNESS

	THICKNESS mm (inch)	STIFFNESS DEFLECTION RATIO
ORIGINAL STEEL SHELL PLATE	6.4 (0.25)	L/313
25 PER CENT WASTED	4.76 (0.1875)	L/132
MEDEA'S PRESENT STEEL	4.45 (0.175)	L/107
MEDEA STEEL WITH FRP SANDWICH	24.3 (.956)	L/156

The deflection ratio stiffness in the table is based on a given deflection over a fixed span under an applied load. Therefore, the higher the number "x" in the ratio "L/x," with "1" being the fixed panel span, the stiffer the panel section. The span for the MEDEA's framing members is 500 mm (20 in) and the applied load was 365 kilopascals (3.5 psi) based on the the head pressure from a mean draft of 2.1 m (7 ff).

Longitudinal hull bending of the vessel was also a concern. Due to the relatively low tensile modulus of the proposed composite repair, one may first assume that the additional FRP skin's contribution to the hull's longitudinal hull bending stiffness was minor. However, because the MEDEA is riveted, the effective plating for bending is reduced by the ratio of rivet hole size to rivet hole spacing, making the contribution of the FRP skins more important. The following additional factors combine to restore sufficient longitudinal strength for the service intended:

1. A wide band of 14.3 mm (9/16 in) solid laminate was planned in the keel area to withstand docking loads;
2. The hull plate below the water was wasted but the side shell and deck plates were still in good condition so that the neutral axis was shifted towards the deck; and
3. Longitudinal hull loading is reduced with the vessel restricted to San Diego Harbor so that severe hull bending due to ocean waves is not a factor.

In an analysis of hull girder bending, the thickness of the FRP plating is added to the steel in the ratio of the elastic modulus. Thus 1/20th of the FRP thickness is effective for hull girder bending and the 4.45 mm (0.175 in) plate gets 1/20th of 7.1 mm (0.281 in) or 0.36 mm (0.014 in) added to it to make the effective thickness 4.81 mm (0.189 in). This addition brings the effective thickness above the 25 per cent wasted minimum of 4.76 mm (0.1875 or 3/16 in) and allows the vessel to retain roughly 90 per cent of its hull girder bending strength.

Part of early plans for repair proposed bonding FRP frames to some of the wasted internal framing members. This plan was dropped in favor of welding new or additional steel frames onto the old frames. Therefore, initial denials to the proposed repair which were based, in part, on fire protection concerns, then became non-issues because all the combustible resin would be applied outside the hull.

The final concern of all parties involved was that the composite remain attached to the steel. Panel bending tests were performed to demonstrate the stress aspects of this question, and Dow Chemical, supplier of the vinyl ester Derakane® SOS4 resin, demonstrated sufficient experience and data to show that the composite could withstand stresses, weathering and marine exposure.

Application Procedure

The actual application of the FRP to the MEDEA was a painstaking manual repair procedure that requires explanation to place into perspective the procedures planned for future similar repairs. All the work was done at Knight and Carver Yachtcenter, San Diego, California. The basic procedure was to:

1. Sandblast the hull to white metal,
2. Brush coat the bare steel with a primer coat of resin,
3. Apply a putty resin to sections of the hull,
4. Vacuum the foam core into the putty,
5. Fair the foam,
6. Apply the FRP outer skin,
7. Fair the outer skin, and
8. Apply the epoxy primer and paint.

Each of these steps will be described in more detail. Then steps to mechanize the process will be explored.

Sandblast the Hull to White Metal and Prime

The repair was performed on an area from the keel to 200 mm (8 in) above the load waterline. To effect this in a continuous process around the bilge and across the keel, the MEDEA was placed on removable blocks under the keel and supported on the sides by pipe secured to the ground and welded to the vessel above the repair area. It was blasted in sections and immediately coated with a primer coat of catalyzed resin to preserve the steel and to provide a prepared substrate for subsequent bonding of the foam. The work was done in sections to:

1. Minimize the area of exposed steel,
2. Reduce the number of keel blocks removed at any one time, and to
3. Expose a reasonable area for bonding on sections of foam.

Apply Resin Putty and Vacuum the Foam Core

The vinyl ester resin was made into a putty by adding a filler of hollow glass microspheres to provide a tough resilient base to bond the foam into, and to fill bumps and hollows, in the pitted steel plate. The vacuum bag process was used to bond the Airex linear foam onto the vessel in sections. For this application, contoured sections of foam were used. Contoured Airex R62.80 foam is in the form of 1.2 by 2.7 m (4 ft by 9 ft) sheets with cross cuts every 32 mm (1.25 in) through 90 per cent of its thickness. This allows the sheets to drape easily over curved Surfaces.

The principles of the vacuum bag process are that the foam core is placed into the putty in areas of 20 - 30 square meters (70 - 100 square feet) at one time. It is then covered by bubble pack to allow air

to flow out then sealed all around with a plastic sheet. A partial vacuum is pulled through the bubble pack which allows outside air pressure to evenly press the foam into the putty until the putty cures. The process is time consuming but absolutely necessary to ensure a thorough bond.

Fair the Foam

With the MEDEA having riveted construction, plate overlaps for riveted connections are inevitable. In addition, there were many areas where the squared sheets of foam could not be cut to fit the curves of the hull exactly. Where the foam was raised up, it was ground and sanded roughly even. Where hollows and cracks were encountered, additional vinyl ester putty was used to fill the areas until a relatively fair surface was presented to apply the FRP skin. The foam was also tapered and faired at the edge of the repair area and in way of sea chests and through hull fittings. Panel stiffness was retained where the foam was ground down because the grinding took place at the edges of the panels where the steel plate overlapped, and not in the center of the panel span.

Apply the FRP Outer Skin. Fair and Paint

The application of the 3 layers of chop strand mat (CSM) stitched to woven roving that made up the FRP outer skin was by a modification of the basic hand laminating process. This is a process of:

1. Spraying catalyzed resin onto the surface,
2. Laying dry fiberglass reinforcement into the wet resin,
3. Spraying more resin onto the dry glass surface,
4. Rolling the composite to thoroughly wet out the glass, then
5. Drawing off the excess resin with a squeegee.

There was one major exception to the normal laminating process. Much of the work was done overhead. This made the work more difficult and messy, but because the interior of the MEDEA was totally intact and in a nicely restored condition, the hull could not be turned over to allow all the laminating work to be done down-hand. Estimates from the repairer are that this added roughly 20 percent to the labor cost of the laminating work.

The fairing of the outer FRP skin was done by

first sanding the FRP surface then applying a series of Pro-Line® epoxy primers and filled fairing compounds and sanding to achieve acceptable fairness. Then final epoxy primer and antifouling paint was applied.

The internal areas of the vessel were also blasted to white metal and thoroughly coated with epoxy primers and paints. Where internal structure was extensively wasted, new frames were "sistered" to the existing structure.

RESULTS

The finished repair to the MEDEA exceeded the expectations of the owners. Besides satisfying the Coast Guard's concerns for certification, the vessel has a more solid feel when underway. The volume of the light weight composite repair gave the vessel more buoyancy, which would normally be a benefit to an older vessel because older vessels tend to gain weight with time from added equipment and structure. However, the San Diego Maritime Museum Executive Director, Captain Kenneth Franke, stated they may need to add ballast to return the MEDEA to its normal draft. An additional benefit from the repair is that the faired surface eliminated the original shell plate overlaps on the underwater surface.

The MEDEA earned back its Coast Guard certificate on April 24, 1991 with special provisions for examining the repaired surfaces for delamination and separation from the steel hull. According to Captain Franke, regular inspections have shown the repair to be in good order.

The entire repair, including docking and undocking, and internal repairs and coatings was completed for an actual cost of \$220,000. However, many factors contributed to keeping this figure fairly low. Parts of the materials were donated or discounted, pier fees at the repair location were waived, and much of the engineering and administrative support was donated. The repairer estimates that these considerations reduced the actual cost by about one half. The repairer also estimated that the \$220,000 figure would probably apply solely to the exterior composite work had this been an unsubsidized commercial contract.

PRODUCIBILITY ASPECTS

The repair that was performed on the MEDEA was done to the technical satisfaction of all the interested and performing parties. However, one item in the installation procedure warrants review for the application of advanced FRP processing

technology in the form of fiberglass impregnators. The details of how these machines work were described by Raymer (8), but the basics are that the dry fiberglass material is pulled through a resin bath to wet out the fabric, then the fabric is applied directly to the mold surface. Advantages of impregnators over normal hand lamination procedures are:

1. The resin is completely and mechanically forced into the fabric,
2. Resin waste is vastly reduced,
3. Spraying of resin is eliminated which reduces volatile organic compound (VOC) emissions and reduces worker exposure,
4. The already wetted material is applied in an almost continuous semi-mechanized process,
5. Laminate structural quality is improved, and
6. Labor savings on the order of 50-75 percent are realized.

However, all existing impregnators are designed to introduce the wetted fabric from above the surface being laminated. For new construction in FRP, this usually involves building the structure from the outside of the hull surface to the inside, using a female mold, or from the outside surface in on a male mold. The MEDEA was basically a male mold that was not capable of being overturned, making the application direction of the FRP outer skin largely in the upward direction.

This problem is not unlike that of applying the fiberglass and epoxy coating used for wooden minesweepers. This coating, or sheathing, is applied to a nearly completed wooden vessel that is, like the MEDEA, not capable of being turned over to allow downhand application of the coating. Application of this composite coating causes similar problems to those encountered in the MEDEA project with the added complication of worker sensitivity to epoxy resins.

This particular problem, that of applying FRP in an upward direction, was addressed by Venus-Gusmer of Kent, WA in a general proposal to Peterson Builders. For a number of reasons, that project was never completed, but preliminary engineering work showed the feasibility of the method. The basic aspects of the process are:

1. Modifications to the machines described in (8) were designed to redirect the wetted fabric out the top of an impregnator;
2. The impregnator was to be mounted on an electric industrial truck- with a telescoping boom; and
3. Resin and catalyst were to be pumped to the impregnator from a remote station and mixed at the impregnator.

Details of the existing costs and projected cost savings for application of this technology to coating wooden ships is not available for release. Projected savings, including labor, reduced disruption time, and reduced emissions are difficult to quantify, but could reasonably pay for the system over 2 - 4 ships.

Such a system allows all the advantages offered by impregnators. Investment in such a system, including an impregnator, pumps and an industrial truck, for occasional projects such as the MEDEA is not likely to be justified. However, much of the equipment is available for lease or could be made available for lease.

CONCLUSION

The FRP cladding of the wasted steel plating on the S/Y MEDEA proved that an adequate repair of a steel structure can be made with innovative use of composites. The sandwich composite structural repair was able to satisfy the concerns of the Coast Guard so that the vessel was recertified. The repair within the financial means of the owners. Even if donations and other considerations were not used, the FRP repair would have cost less than one third that of steel renewals.

Applications of mechanized FRP impregnating equipment could make similar repairs and FRP work an even more cost effective proposition.

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A Future Role of Quality in Shipbuilding - Reducing the Odds

IVA-1

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ABSTRACT

Shipbuilding suffers from many of the problems unique to the so-called made to order industries. These problems are usually caused by the need to use existing resources to produce products to different design requirements and specifications.

The major problems usually result in the inability to predict both the capability of design and production methods to meet the new product requirements. The lack of sufficiently long production runs to justify the development of a prototype to analyze these potential problems, has long been used as a defense for poor performance and high levels of re-work.

Other industries are now using quality techniques, familiar to shipbuilders, to reduce the cost and numbers of prototypes. Toyota in particular is set to reduce new model development by half over the next decade.

This paper sets out a methodology for the assessment of design and production capability as an approach to quality improvement in the shipbuilding industry and addresses the all important cultural factor that is key to the success of any performance improvement program.

INTRODUCTION

The ability to predict, with a high degree of confidence, the outcome of a series of individual manufacturing activities would clearly provide any shipbuilding facility with a competitive edge, as not only will it be better placed to anticipate potential problems, but it will be able to make appropriate time and cost allowances for these problems at the planning stage, to ensure a good estimate of work content and production cycle times as well as specific resource requirements.

The main barriers to making such predictions are twofold:-

- 1) the lack of sufficient control of the manufacturing process to limit the variability of the process; and
- 2) the attitudes of senior management, middle management and workforce towards change and improvements in performance.

If the variations in a manufacturing process can be controlled, then predictions of probable outcome can be undertaken with a considerable degree of accuracy.

If the culture of the company can be changed, then it is more likely that action would be taken to reduce the occurrence of repetitive problems and a platform for continuous improvement can be established.

Thus, the long term target is the elimination of re-work, but the short term target is the management of re-work.

The role of quality is to reduce the odds against factors creating uncertainty about a vessel that is to be manufactured so it can, with a degree of probability, be produced right first time.

There are two distinct, yet related, problems preventing a successful approach to performance improvement. A technical problem based on the development and use of 'HARD' technology to ensure that data is available and analyzed and a 'SOFT' skills approach to ensure that the results of the analysis are implemented effectively and that a culture for continuous improvement is established (1).

This paper reviews both the hard technology of the techniques of statistical problem solving (2) and prototype modelling through the use of variation merging analysis (3) and capability studies (4), as well as the role of the 'soft' skills required to undertake a methodical and logical approach to change in culture and attitudes in an organization.

It is only the combination of both the hard and soft approaches that will ensure that a facility can respond to the ever changing demands created by new designs, modifications and technology.

THE ROLE OF QUALITY

Quality does not just have a role in the production environment of a shipyard, it must permeate every aspect of the shipyard's function, from clerical work to welding, from design to marketing. Each individual must adopt a culture that has the ultimate goal of perfection, through the improvement of company performance. That is to say, that quality and company performance go hand in hand. If a process or function is to be improved, the net result must be a measurable benefit to the company.

The role of quality has been summarized very neatly as the ability to answer four simple questions (5):-

- 1) Can we make it OK?
- 2) Are we making it OK?
- 3) Have we made it OK?
- 4) Can we make it better and if so, how?

Consider performance in any company against these questions, and what these questions require of that company to ensure that ultimately the product is produced efficiently and fit for the purpose, and competitively priced.

Consider the easiest question first: HAVE WE MADE IT OK? This is the traditional role of quality. To answer it requires a checking function at the end of production to determine if the product is of acceptable quality. Not a very efficient approach as by this time, the time and resources have already been spent on corrective unscheduled work to modify the faults created at previous stages in manufacture. It is an important question to answer but in no way reduces the cost already incurred.

Most shipbuilders have reached this point in their approach to quality. The second easiest question to

answer is the ARE WE MAKING IT OK? question. This question can be answered through the use of statistical control charting techniques which are familiar to most shipbuilders (6) (7). In particular, the use of tolerance chain analysis as outlined by Juran (Ibid) and capability studies as outlined by Grant and Levenworth (Ibid).

The benefit of answering this question is that to a certain extent, problems can be resolved at the workstation where they occur, thus reducing cost and time of re-work. The techniques provide a good basis for planned maintenance of equipment, for training of personnel and for the establishment and review of quality assurance procedures, as-well as a first step in the management of re-work because they begin to quantify faults at each workstation.

The next question to answer is the CAN WE MAKE IT BETTER AND IF SO HOW? question. There is always an attempt to answer this question. However, quite often the feedback mechanisms that exist within any organization are inadequate and do not ensure that mistakes or errors are not repeated. This is because the organization does not delegate responsibility or problem ownership but merely goes through the motions of feedback.

Certainly, if a customer wants a modification, this is implemented but often cannot be accurately costed or its effect on subsequent activities quantified.

Finally, the question that should be asked first and the one about which most is assumed, is the CAN WE MAKE IT OK? question. Before the start of a contract, it is naturally assumed that the vessel can be made to the price and time quoted and invariably this assumption is proven wrong because at best the process to be used in its manufacture is not stable enough to be predictable. However, the tools and technology are available (8) that would allow control of processes. These tools have existed for some time. What has not been appreciated is the importance of the soft skills required to successfully implement them.

A closer analysis of these questions indicates that effort to be expended in achieving the answers to them can not be expended equally on each one, because the potential benefits from answering some of the questions is greater than others. What must be developed is a strategy that enables us to address each question in the most efficient way.

The starting point is grasping again some of the basics before progressing to the technology and the skills.

THE ROLE OF THE PROTOTYPE

The concept of arithmetic of errors (9) identifies the fact that, as a mathematical computation becomes more complex, rounding or computational errors, although individually small, can accumulate to create errors so large that they can have a significant bearing on the final result of a calculation. This is exactly the same process that occurs in assembly industries, such as shipbuilding. The individual process errors, although small can, if not controlled, accumulate to such an extent as to make the final assembly difficult to erect. In the arithmetic of errors concept, it is generally assumed that there is a desired value 'n' and, due to errors, an actual value 'N' is obtained, i.e.:

$$n = N \pm e, \text{ where 'e' is the error. (1)}$$

In any manufacturing process, production errors are present. If these errors are not managed or eliminated (controlled), any product produced can only be inferior in quality and reliability, as well as more costly to produce because of the inherent re-work, than a well engineered, designed and manufactured product.

The ideal solution for any new design, would be the production and testing of a prototype before issue of the final drawings. Equally, it is desirable to test the proposed production technology by having a test run or producing an '0' series.

The purpose of a test run is to reveal any errors in the proposed production methods and equipment and then finally, to prove the production technology. It also identifies where re-work may be required and gives an indication as to the quantity and cost of it. The test run is designed in the same way as a production run, using the same technology, jigs, tools, gauges, etc. In the ideal state, normal production would only commence after successful completion of a test run. Thus, by the time production starts, the capability of the production process is understood and its limitations are identified, quantified and costed.

The quality and reliability of an engineered product, depends equally upon the quality of its design and uniformity of production (see Figure 1).

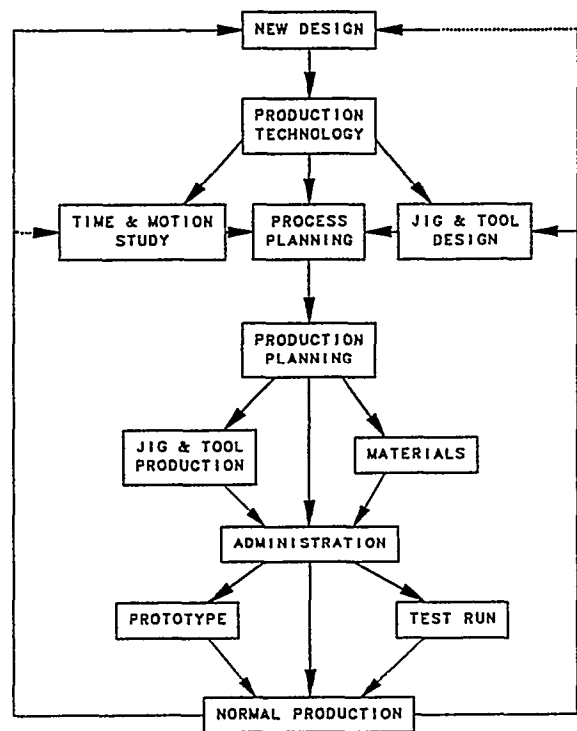


Figure 1 - The Coordination of Design and Production

In large or heavy manufacturing industries, such as shipbuilding, the use of prototype development is impractical, because of the low numbers and large capital cost of each production unit. In these types of industries, the product is generally a 'one-off', thus giving no opportunity to fully investigate the production process, before actual production starts. Consequently, some other method must be adopted to analyze the production process in these industries. Areas that will lead to re-work must be identified before production starts to allow for their management as part of a strategy rather than a fire fighting exercise, hence reducing the odds of encountering unscheduled work and costs.

Although a physical prototype may be economically unjustifiable, an alternative approach is a realistic possibility. The use of merging equations, as identified by Storch and Chirillo in the 80's, clearly indicated that the potential for the development of a theoretical prototype on paper could be achieved. The concept of merging equations is described in detail in those references and not presented here.

Through the use of such techniques and through the application of statistical process control techniques, it is possible to predict

the probable outcome of a series of processes that produce interim and final products.

The degree of accuracy of these predictions is quite remarkable, for what are relatively straightforward calculations. The development of the equations for complex structures can be quite laborious, but once established can be used again and again. It is interesting to note that other industries, in particular electronics, are already adopting this approach as a means of reducing prototype development costs (10).

DESIGN

The Inherent Similarity of Design

In the building of any particular vessel, one of the more common arguments for lack of control of production systems is that the current vessel is unique and quite different from the previous vessel built. Yet this vessel, like the last one, will be built by the same workers, using the same tools and the same processes in the same facilities. If each product was so different, then some major re-tooling or some major re-training program would be necessary.

This does not often happen in shipbuilding, therefore the conclusion that can be reached is that the products are inherently similar because working practices and resources do not alter dramatically from vessel to vessel. This conclusion is supported by references 11 and 12.

The Benefits of Similarity of Design

The mass production industries reap the benefits in efficiency and cycle times by the employment of rigid process lanes with well defined work stations. Balancing of the line is achieved to minimize storage space and work in progress, through the concepts of Time Allocation Techniques and Just in Time procedures. The relatively long production runs justify the financial expenditure inherent in the development of complex and relatively inflexible production systems. A dramatic change in product design can result in considerable facility re-design and re-tooling costs: costs which would only be recovered from another suitably long production run. At the other end of the production spectrum, lie the made to order industries, such as bridge builders and civil construction. Here every product has unique attributes that set it apart from its predecessors, the most important attribute being that of location, with the inherent compromises required to adapt a design

to its environmental constraints.

In between these two extremes lie a number of options (13) based on the type of facility layout and the methods of manufacture employed.

Shipbuilding has traditionally been a mixture of activities: quite high levels of mechanization at the early stages of the process, with a gradual decrease as production moves towards the berth and erection activities. Different but inherently similar products are produced that lie within the product mix of the yard.

If designs can be developed so as to take full advantage of the inherent similarity of the products, both steel and outfit, considerable performance related benefits can accrue to the company employing such techniques. The onus however, must be placed not on the designers predicting and understanding production performance, but on production. Production must ensure that this data is readily available to the designer in a format that can help to design a production friendly vessel. However, it is the responsibility of designers to take into account the implications of this data and to act on it accordingly.

PRODUCTION

The Determination of Process Capability

There are still many shipbuilders who prepare designs for tender without really determining whether or not these designs can be physically produced within budget and scheduled even through the use of straightforward build strategy techniques.

There have been considerable advances in Computer Aided Design (CAD) (14) which have opened up a tremendous new opportunity and need for understanding the capability of production processes, so that appropriate information can be provided to designers to ensure that a design is production friendly. The basic problem is that quite a lot of production information is generally available, but little is analyzed and fed back in a useful form to designers. This leads to designs needing modification as problems are uncovered by production.

The problem with this type of action is that, like all forms of re-work, it takes place after the event. The cost to produce the problem piece has been incurred and now more time and resources are required to correct the error adding to the cost of work and reducing what may well be an already tight profit margin. In addition, because the re-work is not

managed, it is often carried out under the worst possible conditions.

Because most vessels are made up of the same basic components, performance on a particular design can provide useful data in understanding the probable performance on subsequent designs because similar processes and techniques will be used to manufacture it.

If a vessel design is developed without due regard for process capability, re-work will result. Control of schedule and budget then becomes difficult to maintain because the level and degree of re-work likely to result from a particular design decision is generally not quantified.

It is unlikely that re-work can be eliminated over night. Understanding process capabilities is an ongoing process leading to continuous improvement rather than major gains in performance and productivity. If re-work exists, what is required is a method to determine when and how much re-work is being incurred so that it can be taken into consideration and enable either alternative production processes to be considered or design modification to be made in advance to alleviate potential problems. The use of merging equations provides such a methodology.

A yard must understand how it is going to actually build a vessel and where the potential problems lie so that an allowance can be made for those problems that will not be alleviated within the timescale of a present contract.

Through the use of statistical process control techniques and merging equations, a shipyard can develop a prototype in the form of simple calculations that, although not a substitute for a physical prototype, can also provide a good indication of probable performance.

Process Capability

The use of capability charts, enables a definition of the process capability for a variety of processes which can, in turn, lead to the definition of the mean performance through the use of capability charts, X-Bar and R-Bar charts. Examples of typical charts are shown in Figure 2.

The use of these charts, combined with a logical problem solving approach, can provide positive results in a short period of time (2 to 3 months). Often yard personnel are disappointed because a process that has been causing problems can be solved by

attention to basic principles such as good maintenance, adequate training and well defined procedures. This does not belittle the technique, it only provides a firm rationale for the adoption of a methodical approach to problem solving using basic tools such as:-

- 1) histogram
- 2) scatter plot
- 3) brain storming
- 4) control charts
- 5) cause and effect diagrams
- 6) pareto analysis
- 7) check sheets
- 8) flow charts.

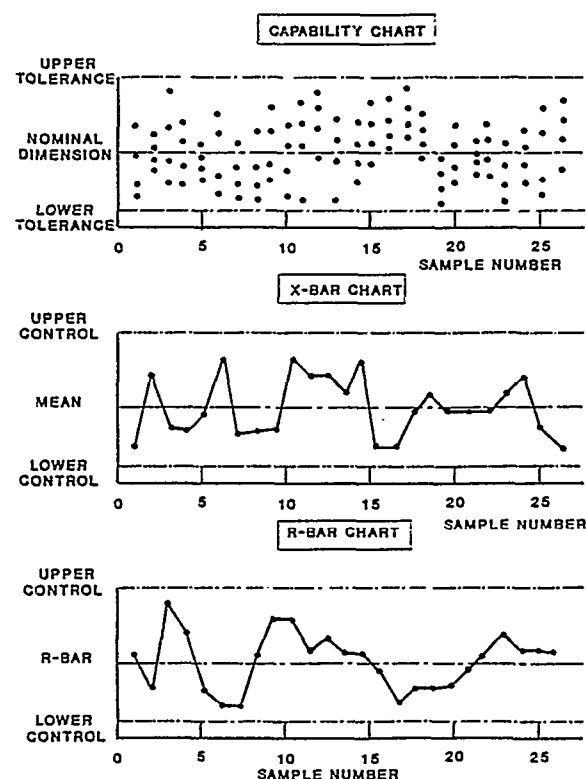


Figure 2 - Basic Types of Control Chart

These tools were designed to be simple to use because they recognize that the majority of problems result from few causes that, once identified and quantified, can be addressed logically. It must again be stressed that this approach does not apply solely to manufacturing activities but to all activities associated with a shipyard.

Use of Capability Studies and Control Chart Data

Properly documented and controlled, the use of capability studies and the results from control charts can provide production a clear picture of the effective limits of probable performance. Re-work levels can be quantified and allowed for at the planning stage if appropriate data is fed back, such that they can be managed to minimise their time and cost.

Control chart data enables the use of merging equations to determine fit up probabilities for a variety of structures and designs. This data, if used properly, can provide designers with a logical set of guidelines that would enable the design of products that can be made ok. It will also provide a sound basis for the review of completed products to genuinely identify methods for making them better next time, and finally, it provides a sound basis for capital investment. A typical program can be represented briefly by the following steps. This shows a simplistic problem solving approach and the options available before expenditure of capital:-

- | | |
|---------|-------------------------------------------------------------------------------|
| Step 1 | Establish current levels of process performance (capability charts). |
| Step 2 | Establish if process is under control (control charts). |
| Step 3 | Identify any special causes for lack of control. |
| Step 4 | Re-define process capability. |
| Step 5 | Review procedures. |
| Step 6 | Ensure procedures are being followed. |
| Step 7 | Define tolerances through tolerance chain analysis. |
| Step 8 | Examine effects of alternative production sequences, using merging equations. |
| Step 9 | Establish if present levels of re-work are acceptable. |
| Step 10 | Can design be make more production friendly? |
| Step 11 | Consider purchase of new equipment. |

It is important to note that these steps represent a dynamic situation. Levels of re-work acceptable at present may not be economically justifiable in the future, as the manufacturing process is continuously

improved and brought under greater control. However, the process recognizes that at times the economic environment in which a company finds itself means that some levels of re-work would initially be justifiable, the main difference being that these levels are quantified and planned for, with appropriate resources set aside to deal with them. It also clearly indicates that many actions could be taken to resolve problems before the expenditure of capital as opposed to the traditional approach which often relies on the availability of capital immediately to resolve problems.

Thus, the data from capability studies and control charts provides a means of quantifying the limits of current performance. Properly fed back to design, it provides a sound basis for genuine design for production to be undertaken and re-work to be managed.

Requirements of Database for the Establishment of Capability

The requirements to establish an effective capability and control chart database can be summarized as:

- define re-work;
- define tolerances and establish tolerance chains;
- identify critical dimensions (global and local);
- set up a data collection system; and
- provide analysis and feedback to production, design and other departments as appropriate.

Some of the above may appear very obvious - it should. There is nothing difficult about using these problem solving tools and the results obtained from them. A typical cycle is shown in Figure 3 based on the Ford Motor Company approach (15). The blitz part of the process indicates the need for initial resources to help gather the start up data. Once the blitz is completed, the process is run by those performing that job.

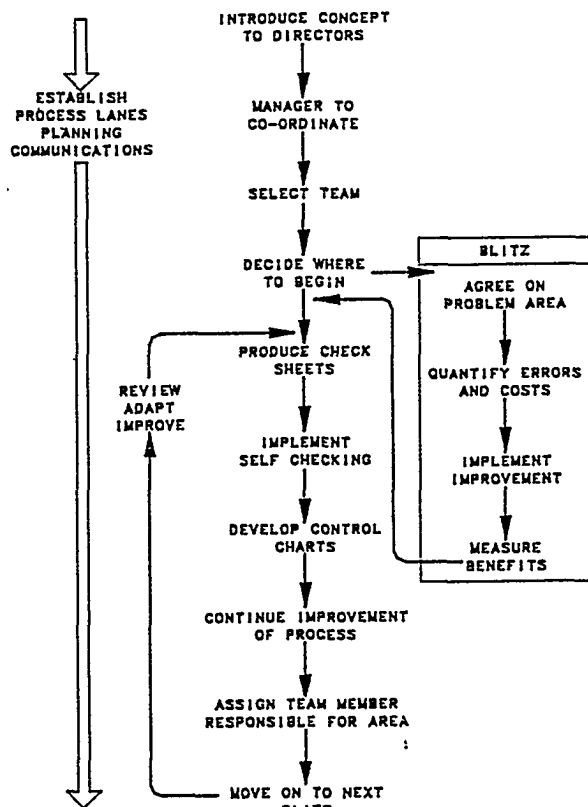


Figure 3 - Implementation Plan

THE BARD TECHNOLOGY

The Basic Requirements

A number of important criteria must be met by any system that attempts to predict design and production performance by mimicking the use of a physical prototype. They are:

- accuracy of prediction;
- speed of prediction;
- compatibility with information and techniques currently in use.

The accuracy of prediction is governed by the accuracy of data available. If an appropriate quality philosophy and culture are adopted, this information should be readily forthcoming from each individual workstation on each predefined process lane.

The speed of prediction limits the number of alternatives that can be examined to optimize a particular design and manufacturing sequence. Consequently, the use of computers enables the rapid calculation of merging equations and enables the appropriate optimization to be carried out.

Finally, compatibility to existing information and techniques means compatibility to existing design methods, in particular if they are computer based. This would provide rapid feedback to the designer to enable him to evaluate the alternatives suggested by the prototype model.

There can be no unique solution. However, an outline of the form of a prototype model that is in line with the philosophy outlined above, has been developed (16). In its present form, it has limited application but its real potential lies in its integration to a CAD facility to provide a complete prototype modelling capability. The program developed is not intended to be definitive, merely to indicate the potential for prototype modelling in ship production and its possible benefits. A flow chart outlining the salient features of the computer program is presented in Figure 4 (Ibid).

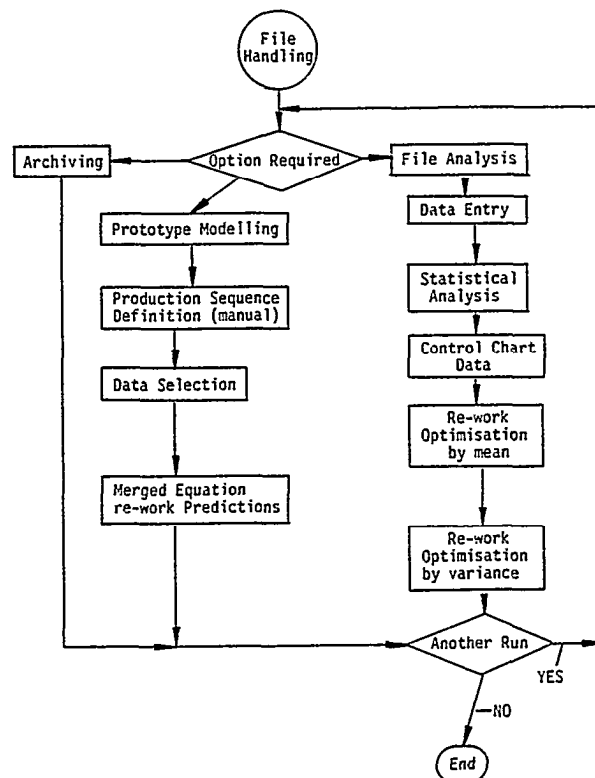


Figure 4 - Flow Chart of Prototype Modelling Program

Future Use of Software and Limitations

The program has been exposed to limited use at a shipyard, merely to prove that the various algorithms and optimization routines work. This test highlighted both the advantages and disadvantages of the system.

The advantages were the speed and accuracy of the calculations it could perform and its ability to provide a quantification of likely levels and costs of re-work to be incurred at each process and at the end of each assembly stage.

Its disadvantage was that this information was being provided after the event, that is, after the design and production sequence had been derived, with little opportunity to alter them.

Clearly, there is a need to provide this information on line to designers, such that once an assembly has been designed the designer can simulate its construction, given a pre-defined sequence of manufacture and current process capability data. This would enable the designer to immediately determine the producibility of a particular structure and also consider alternatives to optimise both the design and the best methods of production. Thus, minimizing re-work and enabling the management of re-work that cannot be eliminated by quantifying it and selecting when and where it is best to deal with it.

Such a link is easy to describe on paper, but pre-suppose a number of key requirements, that:

- data on all processes is available;
- the designer can be provided with this information in a meaningful way;
- the freedom of the designer would be restricted by the need to produce production friendly designs; and
- the culture or soft skills exist in the organization to make full use of such a system.

Thus, the techniques and tools for the management and elimination of re-work are well documented and well proven and relatively simple to use but unless the corporate culture is prepared to adopt them investment in this area is disheartening and wasted as program after program fails.

THE SOFT SKILLS

The Role of the Soft Skills

The techniques and tools for improvement of quality have been in existence for many years and have been applied to most types of manufacturing environment. However, it never ceases to be surprising that upon initial discussions with senior managers at various sites, one of the first arguments put forward for inadequate quality management is the "we are different" argument.

This is not an argument about the applicability of tools. It is an argument that reflects the natural fear of change that many humans share.

The Definition of Culture

In discussing these 'soft' skills, the term culture is often referred to an organizational culture may be defined as:-

"A pattern of basic assumptions - invented, discovered, or developed by a given group, as it learns to cope with its problems of external adaption and internal integration - That has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems". (17)

This is distinct to the term organizational climate which is a measure of the morale or happiness of a staff at any particular time.

Culture thus has both formal (overt) and informal (covert) aspects. As identified in the French and Bell Iceberg model, Figure 5 (18).

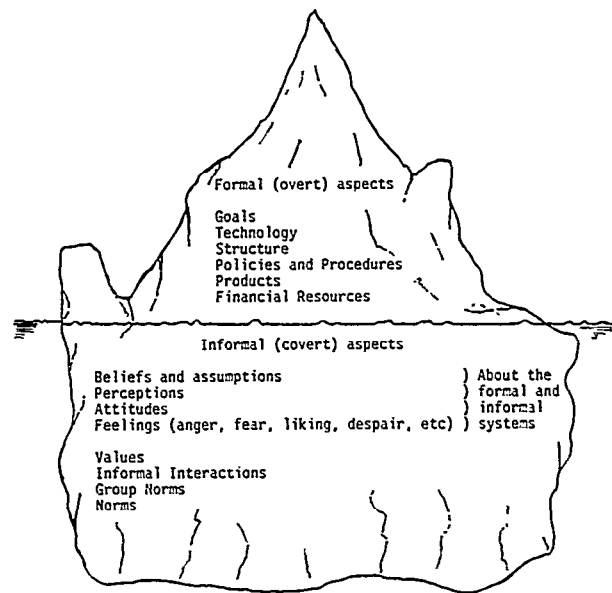


Figure 5 - Organizational Iceberg

Creating the right culture has to be worked at and planned. It is not a short term exercise. There is always a risk in attempting to change culture. Conversely, there is also a risk of sticking with the traditional approach and avoiding change. The traditional approach to quality has stood us in

good stead. The quality improvement approach (Total Quality Management) has been well documented and there are numerous examples readily available of its success in a variety of industries (19, 20, 21, 22). What must be agreed is that shipbuilding is not different.

In the previous sections of this paper it has been shown that problem solving techniques, in particular control charts, can be applied to shipbuilding. Therefore in the 'hard' techniques at least, there is a considerable similarity to other manufacturing industry and indeed some service sectors.

The culture of an organization is created by the people working in it and unless there is some unique genetic trait amongst shipbuilders, the 'soft' skills adopted by other industries should be applicable to shipbuilding.

A Methodology for Change

From an engineering standpoint, it would be extremely desirable if there was some logical step by step program that could be initiated to change corporate culture at the end of a 15 week program. Unfortunately, the nature of "soft" issues precludes this. This could be the reason why most papers on quality improvement focus on the "hard" techniques.

However, there are some key guideline activities that should be considered.

Soft Skills - An Approach

As with most changes in an organization, the commitment of senior managers must be clear and present. Their level and understanding of the problems and the tools, techniques and soft issues must be raised so that they can put the problems they face into an overall framework for resolving them. The initial step is that of planning. Quality improvement is not a flavour of the month activity, it is a way of life for survival and competitive edge. It will not be finished in one month or one year, but will be continuous and involve many small steps. It will be frustrating and incredibly demanding on time.

Initial planning can help overcome problems that could bring to an immediate and premature halt to any thought of progress. So where should that change begin?

A model for change was proposed by Judson (23) and emphasises the importance of communication and

employee participation in change programs. His action plan comprises five phases:-

Phase I

Analyzing and planning the change. This phase will occur before any formal action is taken. It concerns building a clear concept of what is to be accomplished and why together with developing an understanding of how change is likely to be perceived by those who will be affected. It further involves the search for solutions to potential problems.

Phase II

Clearly conveying the objectives of the change so that those effected by it will be aware of the necessity and imminence of the change programs. Communication is a part of the overall program that cannot be over-stressed.

Phase III

It is not sufficient to merely implement the changes. Acceptance of the need to change must be gained from all employees. This stage is a vital step which is carried out before the transition phase is initiated. Four methods adopted to reach a consensus on how to carry out the transition are:

- 1) Rewards
- 2) Bargaining
- 3) Participation, and
- 4) Some combination of the above.

Phase IV

This involves the making of the initial transition in the change process. The following rules must be followed in this phase:

time must be allocated for conducting a trial run of the change and solving unforeseen problems;

supervisors, staff. operatives and managers must be well briefed and have undergone training before the start of the transition;

managers and supervisors must be on hand to resolve any queries or problems that may arise;

specialists who are responsible for providing advice on specific areas must be involved; and

managers must keep abreast of progress so that they will be able to make any necessary modifications.

Phase V

Follow up procedures must be installed which alert managers to unexpected secondary effects, to remain flexible and, at the same time, to be able to evaluate results comprehensively and objectively. The process should also offer opportunity for consolidation of gains made.

This plan offers a concrete basis for change which, if adopted properly, will minimize the resistance of those affected, but it falls short of providing actual techniques for carrying out each phase. By contrast, Beckhart and Harris (24) furnish a detailed tool kit for change agents at the strategic level.

They define a four stage process:-

- 1) define need for change
- 2) define the future state
- 3) assess the present
- 4) manage the transition

and provide ideas of appropriate tools for each stage.

Ford Motor Company on the other hand, in their joint publication, "Opportunities for Change" (25), provide a tool kit for achieving tactical change in work groups. The tool kit provides a set of outlines for exercises, games, team activities that encourage understanding of some of the cultural issues raised when attempting to create change in an organization.

An Approach

The previous section identified theoretical approaches to achieving cultural change associated with practical tool kit applications, but how does this translate in reality.

A good basis for this is to examine within the limited scope of this paper an outline of a possible approach that tries to break down the process into manageable steps (26).

This is not intended to be a definitive approach; the very nature

of its application implies that it will need to be tailored to meet the specific needs of a particular organization.

Step 1

Make clear at the most senior levels that quality improvement is a broad title under which you will be able to address hardware, software and humanware inadequacies in your organization.

Step 2

Define your organization's mission statement, the reason it exists. This should form the solid platform from which the clarity of quality improvement develops.

Step 3

Define your operating principles or basic beliefs.

These are the fundamental bases for corporate culture. They are the things that keep good employees and attract new employees. These must be developed by top management and will change infrequently.

Step 4

Define the business objectives. -The direction of a company over a period of time should be well publicized to provide managers and employees with clear goals for a 5 to 15 year period.

The objectives set by management may change with the prevailing business climate, but should always be well communicated and measurable.

Step 5

Define the performance goals. These are targets that support business objectives and must be measurable and time related. The short term goals should be reviewed each year, by line management and middle management, and tied to appropriate budgets. The goals should be reviewed and approved by senior managers to show support.

Step 6

The strategy to achieve the defined goals needs to be defined. This is the approach to be used to meet the goals generated by middle management. This should be updated but

drastic changes should be avoided, as this leads to excessive expenditure of resources.

Step 7

The tactics to achieve the strategy must be identified. They should be updated once a year and changed frequently. Employees should be encouraged to participate in their development and implementation.

Steps 1 to 6 are top down activities, that is they initially require the efforts of senior and middle management to push them through from the top down until they permeate the whole organization. Step 7 is a bottom up activity, where the employees take the lead in how the targets will be achieved. The employees can only do this if they are provided with the support and training they require.

All tactics have five basic elements:-

1) **Management Action**

If there is superficial support, there will be superficial results.

2) **Process Control**

Defining the limits of processes brings everything under control and makes it predictable.

3) **System Control**

System control should be achieved by documenting the controlled processes and initiating methods for continuous improvement.

4) **Supplier Relations**

Disruptions to the system caused by defective parts and poor services are minimized or eliminated.

5) **Total Participation**

The active participation of all employees in the process. Until that is achieved, success is always going to be difficult to attain.

There are many tools and techniques as identified by the Ford Motor Company (Ibid), IBM (Ibid) Atkinson (27) and French and Bell (Ibid) that provide suitable methods and supporting techniques to enable the successful completion of a change in culture.

The soft skills create difficulty because there is not the rigidity of structure for the change of soft skills that exists in adoption of hard techniques.

What has been presented in this paper are a set of possible guidelines that have been used in other industries and have had limited application in the marine field. Each organization must define for itself those steps that will be the most important and the best approach to them.

CONCLUSIONS

This paper has by necessity covered a broad area to address both technique and skills. However, this is justified because it is important to establish the link between the successful application of hard techniques and the adoption of cultural change through soft skills.

The two go hand in hand, the continued success of an initiative not combining both approaches is unlikely. Some short term gains can always be achieved, but long term success requires a methodical and planned approach to both.

The ability to simulate prototypes using statistical process control and merging equation techniques does provide a meaningful technique for the management and elimination of re-work. The ability to predict before the event the probable outcome, can provide very useful information on time and cost for completion of projects, enabling better estimating and a logical framework for problem solving.

The approaches to cultural change provide a framework for ensuring that the adoption of such techniques fits in with the overall development of the organisation to ensure the long term success in the implementation of new technology.

The major questions about implementation of quality improvement programs are generally focussed upon resources needed for such a development: people, time and cost.

The people commitment requirements should not be underestimated. Quality is too important to leave to a Quality Department; the active participation of all the workforce is critical for success. In return, the workforce must be provided with the appropriate training to enable them to understand the envisaged developments and to provide a meaningful contribution.

The time requirements of quality improvement are dependant on the current corporate culture but there are no "programs" that can provide a short term fix with long term effects. The best advice is to take it in small manageable steps. Do not be overwhelmed by the magnitude of problems; break them down into manageable sizes and no matter how simple the problem is, do not belittle the achievement of identifying it and overcoming it.

Finally, the cost of quality programs is clearly very important. Many of the quality gurus devote considerable time to this subject and rightly so. Unless the program provides a return on investment, why make the investment. Clearly there can be social reasons for keeping people employed or financial inducements to invest the money but a return on investment is still required. Quality improvement reduces both the amount of re-work and the amount of unscheduled disruptions to the production cycle, thus releasing resources to generate a better return on investment.

The money available to an organization is tied up in:

- shareholders capital;
- assets;
- debtors;
- creditors;
- stocks and work in progress; and
- financial reserves.

The aim of improving quality is the reduction of stocks and work in progress, thus releasing money into the system to improve assets, (people, machinery and facilities), so that more income can be created.

The techniques available are well documented by Juran, Storch and Chirillo and simple to apply. The fact that little success has been achieved in their application can only be attributed to a lack of skills in implementing the appropriate cultural changes to ensure long-term success. Now is a good time to start.

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Management of Technological Change and Quality in Ship Production

IVA-2

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ABSTRACT

Ship production, as other manufacturing and assembly activities, must keep up with technology to assure achievement of required productivity, quality, and technological advance expected by an increasingly demanding market place. The ship market has not only become technologically sophisticated, but customers now no longer buy on price alone. They want quality in design, detailing, operability, maintainability, reliability, usability, all in addition to a fair price, reliable delivery schedule and effective follow on service. In other words, the shipbuilding industry is finally emerging as a market conscious, responsive industry aware of user needs.

To perform this newly rediscovered function, shipbuilding has to assure better management of technological change in both product and process technology and assure continuous total quality management from design and production to delivery and follow. Many shipbuilders are new at this because many assumed a seller's market place.

In this paper, the management of technological change and quality in ship production is presented as a formal step by step procedure which should be undertaken at regular (quarterly or at least yearly) intervals to assure that the yard maintains its quality and performance in process and product terms.

INTRODUCTION

The rapid technological change both shipbuilding products (ship technology) and ship production technology, as well as the increasing pressure of changes in the availability and costs of factors or resources used requires a more effective, timely and responsive management of ship production technology. As noted in other industries, changes in product and

process technology are invariably tied to demands not only for improved product quality, but total quality management. In this paper, we review the major aspects of effective management of technological change and total quality.

Technological change which for a long time was more an issue of prestige and capacity than a management decision based on the need for performance in financial, quality, and product effectiveness terms, is finally emerging as the single, most important function of shipyard management.

Similarly, quality - which for too long implied meeting (often minimum acceptable) standards - now means achievement of near perfection in product design, process and assembly performance, schedule, and product delivery and backup. In other words, quality now means meeting customer requirements and expectations.

Zero defect or achievement of the highest quality possible in processes does not by itself constitute quality performance. It includes the effectiveness or fitness for use of the product (the ship), it includes quality of management from design to post delivery customer support, and it includes a never ending striving towards greater perfection. It also involves quality in organization, team work, and interpersonal relations. As a result, quality performance improves the motivation and commitment of all in the organization to improvements in performance. In other words, effective technological change (in product, management, procedures, and processes), and total quality are interdependent.

Over the years the link between technological change and quality has been forged by people like:

- Deming in Statistical Process Performance Analysis;
- Ishikawa in Methods of

Evaluation of Process Outcomes; and,

- Taguchi in the Analysis of the Consequences of Quality.

Several myths, particularly in shipbuilding, have been that workers lack commitment and integrity, that it is difficult to install incentives, and that shipbuilding is not suitable for introduction of advanced process and management technology. Furthermore, many have felt that it is a craft type industry in which total quality is difficult to manage because there are so many unknowns.

The fact is that this is precisely why the industry can benefit more than others from effective technology and quality management, as noted from the productivity and quality improvements achieved by high labor cost countries such as Japan and Germany who have introduced thousands of robots and other advanced product design and process technology equipment to achieve major improvements in productivity and total quality.

THE PROCESS OF MANAGING TECHNOLOGICAL CHANGE AND QUALITY

Managing technology and quality requires continuous updating of situation audits in which the existing performance of technology and people (including procedures, etc.) is evaluated in order to determine how well these most important factors perform. Table I is a simple listing of the major steps used in the management of technology and quality. In today's environment, large enterprises and particularly shipyards must update their situation audit at regular intervals by determining their situation audit at regular intervals. A typical outline of a situation audit is shown in Table II. After the condition of the shipyard has been established, its objectives in financial, product, market share, and in other terms must be reviewed.

The performance of the currently used technology and the application of resources in its uses can best be determined by computing both total and partial factor productivities for individual processes, process centers, and the whole shipyard (complemented by computation of the total and partial productivity learning curve to determine the current and expected future role of change of productivity) by tracking productivities from audit to audit. This also provides effective signals of impending changes and projections of possible improvements in performance, if any. This is particularly important in shipbuilding where shipyards seldom

TABLE I - MAJOR STEPS IN THE MANAGEMENT OF TECHNOLOGY AND QUALITY

1. **Technology Situation Audit**
 - Determination of Market Niche
 - Performance of Existing Technology
 - Availability and Cost of Factors
2. **Objective Review and Setting**
 - Evaluation of Market (Product) Market Share, Economic and Strategic Objective
 - Setting of non-conflicting multi-objectives
3. **Technology Evaluation & Forecast**
 - Identification of Product and Process Technologies
 - Forecast and Evaluation of Technology Developments
4. **Market Demand**
 - Establishment of Market-Product Demand,
 - Establishment of Market-Quality Demand
 - Establishment of Competitive Market Factors
5. **Setting a n d Reevaluating Constraints**
 - Analysis of Regulatory Constraints
 - Analysis of Financial Constraints
 - Analysis of Environmental Constraints
 - Determination of Labor and Resource Availability Constraints
6. **Threat and Opportunity Analysis**
 - Identification and Quantification of Threats and Opportunities
7. **Technology Feasibility**
 - Determination of Basic Feasibility
 - Determination of Constraint Feasibility
 - Determination of Competitive Feasibility
8. **Selection of Technology for Change**
 - Selection of Decision Requirements
 - Expert Choice Modeling
 - Comparative Performance Evaluation
9. **Management of Technological Change**
 - Planning and Management of Technology Transfer
 - Technology Implementation

TABLE II - SITUATION AUDIT

1. Current performance of organization, plant, processes, resource use, etc.
2. Position in learning curve of different technologies in use.
3. Availability and cost of factors (labor, capital, subcontractors, services, etc.).
4. Place in market - Product acceptance - Market niche.
5. Organizational condition-Manpower status - Public acceptance.

benefit from long runs of near identical products. It is therefore important to track changes in productivity with changes in product, and use these results as a guide to marketing, to prevent sliding into markets a particular shipyard which may be ill equipped to compete, as shown in Figure 1. The learning curves also help to show the stage of development of the technologies in use and the potential for further improvements.

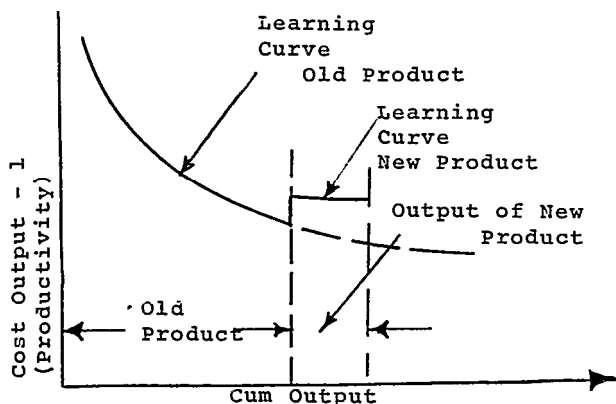


Figure 1 - Change in Learning Curve with Product Change

Although learning curves do not indicate the diffusion or state of innovation of the technology per se, they do indicate if and when technology in use will no longer offer improvements. Similarly learning curves of competing technologies provide an effective means for determining their state and potentials. This is important particularly as we normally know the state of the technologies on the "S", or

technology development, curve when first introduced (Figure 2).

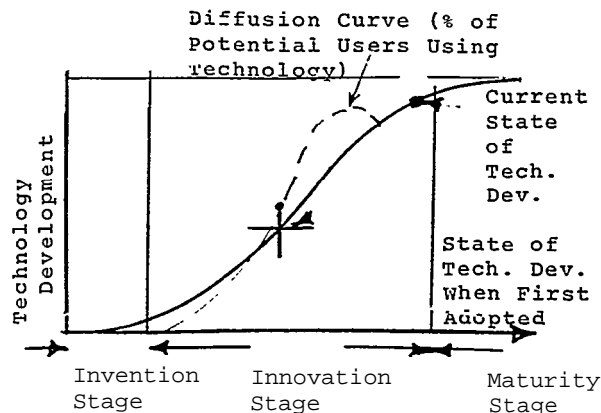


Figure 2 - Technology Development Cycle

This permits an evaluation of our use of the technology. In other words, did we move down the learning curve in line with the technology improvements on the "S" curve achieved during the period since introduction of the technology in our plant?

The availability and cost of factors are determined in both real and current terms and include evaluation of their accessibility. Here one must also determine our factor costs in relation to that of competitors. The place in the market is determined in both absolute and relative terms. Finally, review manpower availability, organizational structure, staff morale, and teamwork is required.

The next issue is the reevaluation of the yards' objective. Traditionally this was simple short term profit maximization, but one increasingly finds that objectives cannot only be financial and should certainly be medium to long term. They should include market penetration and share, product uniqueness, and other strategic goals which advance financial objectives indirectly. The objectives should be clearly stated and have associated metrics in absolute and comparative terms, to permit testing of the impact of changes on the overall multi-objective function.

Technology evaluation should be a continuous activity in which both product and process technologies are tracked in terms of their state of development, performance, and demand. New potentially useful product and process technologies should be identified (often in completely unrelated fields). To forecast technological developments, cross-impact analysis is useful, supplemented by technology development ("S" curve)

analysis, to determine the status and trend of development of a technology on the basis of the factors driving that technology's development. This often includes estimates of the diffusion of the technology both within shipbuilding and the shipbuilding market, as well as in other sectors.

such technology status audits should be performed regularly, and information on technology developments recorded in a standard and usable form. The result of this stage of the management analysis should be sets of "S" or technology development curves with the current state and associated diffusion achieved by the respective technologies, as shown in Figure 2.

Market demand is next determined in terms of product characteristics, quantities, and quality. Price/quality relationships should be established and related to process technology requirements and costs. Similarly, competitive market factors must be identified in terms of product, quality, quantity, price, and delivery time. These results can then be used to establish demand curves, which in turn permit computation of demand elasticity with respect to product technology (ship type, etc.) price and quality. Deployment or Quality Function Deployment is a widely used tool to translate "the voice of the customer" into product and process characteristics, and to develop comparative market analyses.

Next, all the constraints in terms of regulations, financing limits, labor and resource availability, work rules, and more must be defined. A typical shipyard situation audit lists the:

1. work in process;
2. material inventory by volume and value;
3. cumulative and marginal cost of work in process and materials inventory;
4. order book (volume and value);
5. current process productivity and status on learning curve;
6. resource (processes, facilities, workforce, etc.) use and percent utilization of capacity;
7. relative process productivity or comparative costs (when compared with major competitors or in case of material or service supplies with costs of alternative suppliers);

8. current constraints such as credit lines, costs of capital, availability of labor, work rules, environmental protection requirements, etc.;

9. market position, market share, etc.;

10. current organization, decision structure, MIS, etc.; and

11. other.

This concludes the situation audit and establishes the existing conditions as well as the trends and opportunities. It also permits identification of potential threats (such as obsolescence of currently used technology or product lines).

The shipyard is therefore now in a position to define near term as well as strategic threats and opportunities and associate these with resulting consequences (given they materialize), assuming the present state, in terms of resource use, market, and operations, is maintained by the shipyard.

At the same time, ranges of possible outcomes, resulting from the implementation of various new strategies, are defined based on actions taken to counter threats or advance benefits offered by opportunities. A formal approach to such a threat/opportunity analysis is given in Reference 1.

The actual management of technological change is now set to be performed. This usually starts with a technology feasibility determination. One attractive approach to determine the feasibility of various technologies within resource constraints is to use a technology performance diagram as shown in Figure 3. Assuming the isoquants of all alternative technologies are known in terms of limited resources, such as capital and labor, it is easy to determine the feasibility of alternative (process) technologies as certain required levels of output (isoquant levels), thereby eliminate those technologies which cannot be feasibly used within these constraints, and which otherwise would result in their operating below their most efficient levels.

Assume for example that semi-automated welding technology B is currently in use with an optimum (least cost) level of operation at the required output q_1 at which the isocost of say C_1 is tangential to the isoquant q_1 and the expenditure for labor is equal to that for capital and both consume C_2 .

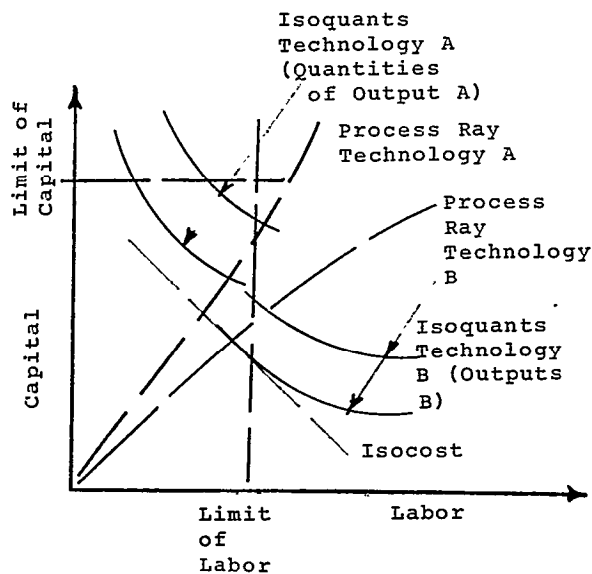


Figure 3 - Technology Performance Diagrams

A new automated welding process, technology A, with a greater learning (productivity improvement) potential now becomes available. For an output of q_1 it also requires a cost of C_1 , but capital expenditure at this time is $2C_1/3$, while labor costs are only $C_1/3$. While a switch to the new capital intensive technology A may not provide immediate advantage, improved productivity and potential future increases in labor costs may make a change over to A quite attractive.

In addition to the resource constraint, feasibility, quality, cost (or productivity), and similar constraints must be determined. Then only process technologies which satisfy all these feasibility requirements are maintained among process technology choices. Similarly, potential product technologies must be subjected to market demand feasibility, price feasibility, and related tests to be maintained in the choice list. Here it is found useful to compute traditional microeconomic demand curves not only in terms of volume of demand as a function of price, but also include demand as a function of performance, quality, etc. and in turn relate price (or cost and profit) to performance and quality and the resulting impact on demand. In most cases such demand feasibility can be determined by use of traditional marketing procedures.

Finally, the stage is reached at which selections can be made from among the process and product technology choices identified, which passed the feasibility test. For this purpose, it

is advisable to use an expert choice decision model (described in more detail in another paper by the author).

Such a hierarchical model permits the introduction of all the feasible technological alternatives (for particular problem or market), the various outcomes, the threats and opportunities possibly affected by the choice of technology for that purpose, the various performance measures, and, finally, the outcomes of objectives conditioned by the choice of technology and materialization of a threat or opportunity.

Sometimes there is more than one decision maker involved such as in product technology choice where users, owners, the shipyard, and investors may all place different weights on the various objectives.

Using a method of pairwise comparative weighing, the priority each decision maker places on each technology can be determined in terms of its

- a. performance (quality, output, etc.),
- b. cost,
- c. effectiveness to counter threats or take advantage of opportunities, and
- d. importance of objectives to the decision maker.

In this manner, the alternative technologies can be ranked and an effective choice can be made. Now remains only the management of the actual transfer and implementation of the technology.

CONCLUSIONS

The formal approach to the management of technological change decisions in processes and products is particularly important in shipbuilding where process and product changes usually involve large investments and resources and long term commitments. It is therefore important to assure that technological change decisions are made formally, rationally, and based on the best knowledge of one's own condition, technological opportunities, impending opportunities and threats, existing and future constraints in such a way as to most effectively advance the objectives of the shipyard.

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Improving Your Competitive Position Through Total Quality Management (TQM)

IVA-3

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Overview

Today we see Total Quality Management (TQM) surfacing as a requirement in government and industry solicitations, such as Requests for Information (RFIs), Requests for Proposals (RFPs) and Requests for Quotes (RFQs). This new requirement, resulting from many activities propagating throughout industry and government, influences the contractor/customer relationship profoundly.

In the past, the subject of quality has typically been reserved for manufacturers. This is changing, however, as stringent quality guidelines surface in solicitations and contracts involving professional and other services. We also see changes occurring in quality requirements that traditionally influence the prime contractor/sub-contractor relationship. Quality companies now realize they can push their own quality efforts just so far before they must turn to their providers of goods and services to continue improving their own operations.

Today's TQM requirements do not circumvent traditional quality requirements, such as MIL-I-45208, MIL-Q-9858, NHB 5300.4(1B), FED-STD-368, ANSI/ASME, or NQA-1. Rather, TQM causes a movement away from traditional Quality Assurance (QA)/Quality Control (QC) functions and applies system-related factors to the process that can be directly tied to America's quality standard of excellence, the Malcolm Baldrige National Quality Award.

Background

Organizations move toward quality for a variety of reasons. It should be noted that most do not make the change without cause. In the private sector, customer expectations typically prompt the changes. Remaining competitive in today's global economy requires an increased level of product and service quality at lower cost. In government the motivation often arises from Presidential Order #12552, or more importantly, constrained budgets.

The standard scenario in government is an increase in customer expectations and, at the very same time, a decrease in the resources available to provide these services. In some instances, TQM is viewed as a vehicle to do more with less. In other instances it is perceived as a means to prioritize business practices and reallocate resources to meet the greatest (or most promising) needs to ensure survival. This has profoundly impacted governments manner of doing business, where the terms "customer," "strategic planning," and "competition" are often new terminology.

Introduction

We can define TQM as:

"A cooperative form of doing business that relies on the talents and capabilities of both labor and management to continually improve quality and productivity using teams."

Embodied in this definition are the three ingredients necessary for TQM to flourish in any company: (1) participative management, (2) continuous process improvement, and (3) the use of teams.

Participative management arises from practicing TQM. Arming employees with the skills and support to better understand how they do business, identifying opportunities for improvement, and making change happen, allows participative management to flourish. Recognizing the capabilities and contributions employees can make begins to chip away at the traditional barriers separating management and labor. Those first few steps toward participative management occur slowly; momentum builds gradually. Traditional barriers between management and labor must be breached by an entity willing to take the plunge and offer a show of faith. That is management's responsibility.

Continuous process improvement means accepting small, incremental gains in the right direction toward Total Quality. Substantial gains result from the accumulation of many seemingly unimportant improvements whose synergies yield tremendous gains over the long run. Continuous process improvement reinforces a basic principle of TQM—long-term focus. Corporate leaders must be willing to invest in Total Quality today, recognizing that big gains may lie in the future.

Finally, TQM involves teams. Each team includes a cross-section of members representing some part of the process under study. This includes the person who works within the process, the supplier of services and materials brought into the process, and its beneficiaries, the customers. Through training, people learn to recognize opportunities for improvement within our company, understand our business practices, apply a structured approach to problem solving, and offer management recommendations on where to apply scarce resources first, to realize the greatest gains. This approach empowers people directly involved in the day-to-day operations of the company to improve their work environment and aligns them with the corporation's goals for

improvement. This personal commitment is achieved in exchange for individual and team rewards, recognition, and job security.

Standards of Excellence

Two basic standards of excellence exist for quality—the Malcolm Baldrige National Quality Award (MBNQA) in the private sector, and the President's Quality Improvement Prototype (QIP) Award in the public sector.

The Malcolm Baldrige National Quality Improvement Act of 1987 establishes an annual United States National Quality Award. The purposes of the Award are to promote quality awareness, to recognize quality achievements of U.S. companies, and to publicize successful quality strategies.

The Award formally recognizes companies attaining preeminent quality leadership and permits them to publicize and advertise their awards. It encourages other companies to improve their quality management practices in order to compete more effectively for future awards. The published Award criteria serves as quality improvement guidelines for U.S. companies. Furthermore, the dissemination of non-proprietary information about the quality strategies of the Award recipients spreads the message that quality is achievable.

The evaluation is based upon seven examination categories:

- 1.0 Leadership
- 2.0 Information and Analysis
- 3.0 Strategic Quality Planning
- 4.0 Human Resource Utilization
- 5.0 Quality Assurance of Products and Services
- 6.0 Quality Results
- 7.0 Customer Satisfaction

The President's Quality Improvement Award criteria differ from the Malcolm Baldrige criteria in one important area. The Malcolm Baldrige Award favors customer satisfaction as the ultimate goal, whereas the Prototype Award focuses on quality results. Therefore, while the standards differ somewhat, the final

analysis of quality is very similar. This common understanding of quality helps people develop the quality-related criteria for RFIs, RFPs and RFQs.

Trends in Quality

Government's movement toward TQM is prompting a re-evaluation of the traditional roles of inspection, testing, planning, and supplier relations. The Federal Acquisition Regulations have not kept abreast of this change, although the interpretation of this information has placed a much greater burden on the Contracting Officer.

Inspection, a well-known term in the quality arena, takes on new meaning as we move toward TQM. Traditionally, inspection meant examining and testing supplies or services to determine whether they conformed to the contract requirements. A movement toward TQM dictates a change to quality audits and process certification. An audit, in sharp contrast to an inspection, fosters a participative ethic between customer and contractor, recognizing that they both work toward a common goal or outcome. The police-action attitude typically associated with inspection is replaced with education on behalf of both parties.

A contractor might look for several indicators to determine if the customer is moving toward TQM. These can include specific terms such as vendor reduction program, vendor certification/qualification, quality audit, partnering, and strategic supplier. Educated customers realize they no longer can afford to bear the costs of OUR mistakes, nor do they have to. And as a company evolves through the process of TQM, it will expect help from suppliers in the pursuit of increased product and service quality. So if your customers are describing their implementation of TQM, you should realize they will expect you to participate.

Developing Quality Requirements

Guidance compelling us to use TQM in our source selection process begins at the

highest levels in industry and government (Figure 1). This guidance has propagated throughout the procurement process, surfacing in RFIs, RFPs and RFQs. Figure 2 provides an example of how to develop TQM requirements and describes the methodology.

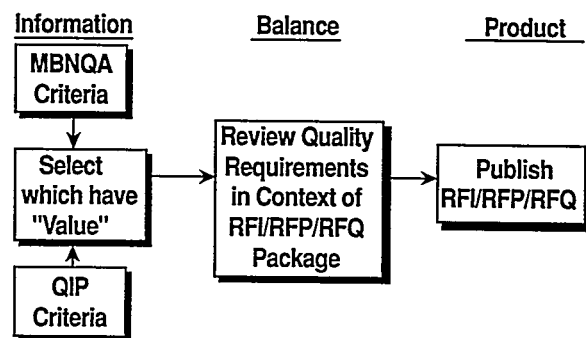
Figure 1.
Example of TQM Guidance

"It is critical at this time that the Department of Defense (DoD), its contractors, and their vendors focus on quality as the vehicle for achieving higher levels of performance."

"I am giving top priority to the DoD Total Quality Management (TQM) effort as the vehicle for attaining continuous quality improvement in our operations, and as a major strategy to meet the President's productivity objectives under Executive Order 12552."

Source: Secretary of Defense Letter Dated Mar 30, 1988
Subject: DoD Posture on Quality

Figure 2.
Formulation of Quality Requirements for Solicitations



Developing quality requirements involves three steps: information, balance, and product. Information (or guidance) in this area is the Malcolm Baldrige or QIP criteria. Here you select the factors you consider to have value. They could be top management involvement, training, processes targeted for improvement, measurement, or others. Balance considers your quality requirements in context of all other factors involved, such as technical merit, on-time delivery, or cost. Here the relative point assignments are made and the "value" associated with quality determined.

In today's environment, as quality increases in importance, it often accounts for a significant portion of the technical or management points awarded in the proposal evaluation process. As the final step, the RFI/RFP/RFQ is published and shipped to the contractor for consideration.

Figure 3 provides an example of one RFQ criterion for distribution services. Here quality accounts for 205 out of a possible 700 technical points. In this case the factors equating to quality in the eyes of the customer include training, relevant experience, policies and procedures, and management commitment to quality. Some of the factors are subjective and descriptive in nature, such as management commitment, where you discuss your direct involvement in the quality process. In addition, you describe your leadership style, which encourages the participative ethic embedded in the definition of TQM.

Figure 3.
Example RFQ Criteria for
Distribution Services

Date of RFP: August 1990		Customer: DOE Contractor	
Category		Point Assignment	
10.0	Quality Control Program		
10.1	Training	30	
10.2	Experience	30	
10.3	Policies and Procedures	30	
10.4	Management Commitment to Quality	30	
10.5	Flow Diagram	25	
	a) Tasks	20	
	b) Monitored Processes	20	
10.6	Tracking Costs	30	
Total Points for Quality Program		205	
Total Technical Points		700	
Total Proposal Points		1,000	

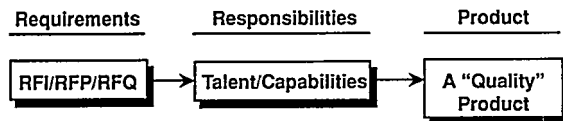
The more technical requirements, such as a flow diagram, require you to describe your processes. Here, you describe the processes you will use to accomplish the work under bid. Flow diagrams, or flow charts, provide a graphic means for depicting the steps you will take to accomplish the work. Other factors considered in this area include establishing logical starting and ending points in the process, establishing metrics, monitoring these factors on a regular basis, and comparing your performance to others with similar processes.

Responding to Quality Requirements

When developing a proposal in response to an RFI/RFP/RFQ with a quality requirement, three logical places exist for describing your TQM approach. They are the cover letter, a section on TQM, and what I call the thread of credibility. The cover letter is a logical first step for communicating your movement into the quality arena, whether it is an RFI/RFP/RFQ requirement or not. In a section devoted to quality, you can describe your approach, explain how you are encouraging your people to practice these skills, and discuss the progress you have made thus far. The third place for mentioning your quality approach is the most subtle, yet the most powerful. It weaves the concepts of leadership, measurement, work flow, and other factors throughout the entire proposal. This approach reinforces TQM as a system of doing business, which touches the technical, administrative, costing, and other facets of your business practice and proposal sections. This third approach, although most indicative of the TQM philosophy, assumes a certain sophistication on behalf of the party reading your proposal and should be accounted for in your decision-making process of where and how you will place TQM in your proposal.

Figure 4 shows the three basis functions performed in the proposal development process: requirements, responsibilities, and product. The requirements are read in the RFI/RFP/RFQ and interpreted based upon your knowledge of the customer. Your ability to address these requirements is also assessed in comparison with that of your competitors, which will influence your decision to bid on the work. After assigning responsibilities to your in-house and hired talent and allowing for appropriate reviews and adjustments, you can converge on a final product.

Figure 4.
Proposal Development Process

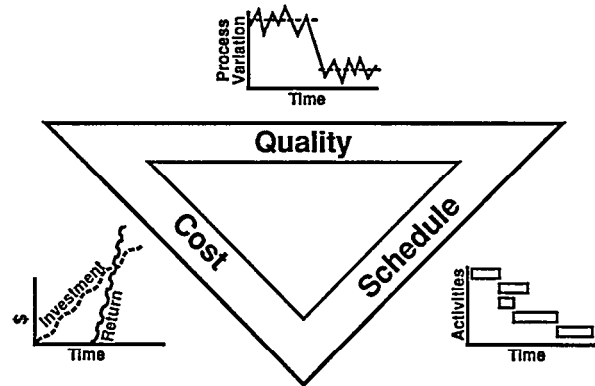


A "Quality" Product = The "Best" product you can produce which "meets" the customers' requirements and "exceeds" their expectations.

Probably the greatest value TQM offers at this stage is its application to the proposal development process itself. TQM can help your team develop more quickly. Disconnects surface earlier in the proposal development process, so you can converge on a second-or third-generation product which will cast your company in the most favorable light. Remember, *quality in the proposal development process means creating the best product you can to meet the customers' requirements and exceed their expectations.* In today's economic climate, merely meeting the customer's needs is simply not enough. innumerable procurement actions have been unsuccessfully contested by companies who had written a 'good proposal' and merely "answered the mail."

TQM has caused us to re-evaluate many facets of proposal writing procedures. One area routinely surfacing as a difficult point is your definition of quality for that specific work, as shown in Figure 5. Traditionally we have considered cost and schedule as synonymous with quality. Today, TQM forces us to consider other metrics for quantifying performance. In the professional services area, for example, quality may be a quantification of the accurate processing of change orders. In the distribution industry, quality may mean accurate delivery of 95% of ordered items within 24 hours of receiving the order. In the manufacturing industry quality can mean demonstrating your processes are in control, certifying the quality of your delivered product, and alleviating the need for your customer to inspect it. Though quality is not always specified in the RFI/RFP/RFQ, it is an important part in your document.

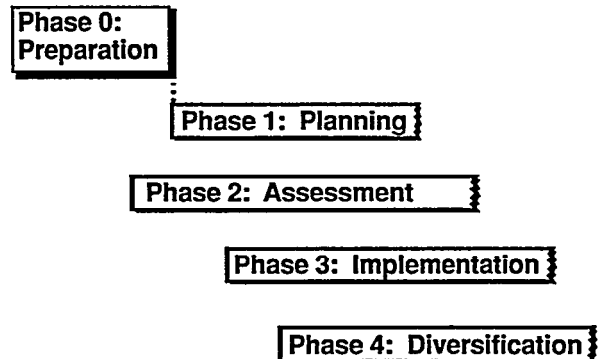
Figure 5.
Definition of Quality



Implementing TQM

Figure 6 provides an overview of the five-phase process to implement TQM in your company (Jablonski,1991). As you can see, Phase 0 is unique in that it has a definite beginning and end. This differs from the other phases, which evolve over time and go on continuously.

Figure 6.
Five Phases to Implement TQM



Successful implementation of TQM begins with Phase 0, Preparation. It is termed Phase 0 because it actually precedes a building process involving the organization's Key Executives. Here, Key Executives develop the organization's vision statement, set corporate goals and draft policy in direct support of the corporate strategic plan. Phase 0 concludes with a commitment of resources necessary to plan the implementation of TQM.

The beginning of Phase 1, Planning, lays the foundation for the process of change within the organization. Individuals who will make up the Corporate Council use the statements developed during the Preparation Phase to begin the meticulous planning process. Once formed, the Corporate Council develops the implementation plan, commits resources and makes it a reality. The planning process relies on inputs from all subsequent phases to help guide its implementation and evolution.

Assessment, Phase 2, involves the exchange of information necessary to support the preparation, planning, and diversification phases. It consists of surveys, evaluations, questionnaires and interviews throughout the organization at all levels, as well as self-evaluations assessing individual and group perceptions of the organization's strengths and weaknesses.

Phase 3 is Implementation, where the investment made during the previous phases pays off. A well-defined training initiative for managers and the workforce begins. With the full support of the Corporate Council, Process Action Teams (PATs) are chartered to evaluate and improve processes and implement change, using the tools of TQM.

The final step, Phase 4, is diversification. Accomplishing Phase 0 (Preparation) through Phase 3 (Implementation) provides the organization with a substantial knowledge base: Policy has been defined, objections to change have been overcome, and success stories may already be reported by PATs. At this point, with newly acquired experience, other parts of the organization should be invited to participate. This may include subordinate organizations, strategic business units, subsidiaries, off-site divisions, suppliers, vendors, or various departments within the organization. Diversification is recommended after the parent, implementing organization, has earned credibility.

Conclusions

The times they are a changing. Government and industry movement toward TQM profoundly influences the manner in which we all will be expected to do business in the near future. The term, "strategic supplier," is becoming a routine way of doing business, and as this trend continues fewer contractors will have larger workloads. Seeley Enterprises, a supplier of sheet metal and high-precision machined parts to the defense industry, recently weathered a ten-times reduction in their customers' supplier numbers. This degree of reduction is not uncommon for major companies moving toward TQM. So if your customer is beginning to plan for the implementation of TQM, it may be time for you to consider its application in your organization. To wait may be too late.

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Using Fiber Optics for Laser Cladding

IVB-1

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ABSTRACT

In many Navy structures, there are many large components that are coated for wear protection (valve seats) and/or for corrosion protection (hatch seals) that require periodic refurbishment. This refurbishment is normally accomplished using conventional arc welding processes which in many cases require that the part be removed from the structure to properly control the pre-, interpass and post-weld temperatures as required by the materials used. The removal of such large components, the thermal requirements, and the resulting distortion can greatly increase the cost for refurbishment.

The Navy Manufacturing Technology Office (MANTECH) of the Office of the Assistant Secretary of the Navy has been funding two major programs through Mare Island Naval Shipyard, Naval Sea Systems Command (NAVSEA 5142), and the Applied Research Laboratory, The Pennsylvania State University (ARL Penn State) to decrease such high refurbishment costs. The first program is the development of high powered laser cladding processes for the refurbishment of components that can be removed from the ship and into a laser materials processing facility. The second, and the primary topic of this paper, is the development of a shipboard laser materials processing system that utilizes fiber optics.

INTRODUCTION

As the age of the U.S. Navy fleet increases and efforts are being made to prolong the life of surface ships and submarines, the cost for refurbishment has increased substantially. One source of this increased cost is due to the refurbishment of worn and corroded parts. These parts must be refurbished or replaced, both of which are expensive and time consuming. In a refurbishment, the worn/corroded areas must have material added so that the part can be machined to meet the dimensional requirements. Examples of such parts include valve seats (Figure 1), bearing areas, shafts, hatch seals, and through hull



Figure 1.
Example of valve component that is candidate for laser cladding operation. Base materials are carbon steel and 416 stainless steel. Clad material would be Stellite 6.

penetrations. Many of these parts have very stringent dimensional requirements which are difficult to meet if conventional arc welding processes are used due to the thermal distortion characteristic of the process. Also, many of the cladding materials and the base materials require pre-, interpass, and post weld temperature controls (MIL-STD-278) which are not always possible during shipboard refurbishment. It is therefore very common for parts to be removed from the ship for refurbishment. This removal can be very costly, especially for submarines, where many of the components that require refurbishing do not fit through existing openings.

In addition to the problems related to the distortion of the parts, some of the cladding materials that are used are not very weldable. Such materials include cobalt based alloys (e.g., Stellite 6) which are used to hardface valve seats. The weld cladding of the valve seats with such materials can become very expensive if repeated cladding and machining is required to

remove defects. Many of the problems with these types of cladding materials are related to the high temperature ductility which is related to the segregation, dilution, and/or cooling rate of the process used.

The implementation of lasers in industry has occurred in the last twenty-five years. Industrial lasers are normally one of two types gaseous (e.g., CO₂) or solid state (e.g., Nd:YAG) (1,2,3,4). Each type of laser may differ in design and/or operation based on the power required and the type of process that is to be performed. In both laser types the coherent, collimated, infrared light that is produced can be focussed to a very small diameter and therefore very high power densities can be achieved (10^5 - 10^8 w/cm²). Such high concentrations of energy results in low total heat input to accomplish the desired material processing (e.g., laser cutting, cladding, or welding). For example, 12.7 mm thick HY- and HSLA steel plates have been laser welded without filler metal at approximately 20 kJoules/in of heat input. The interaction characteristics between the laser beam and the material are very similar to electron beam processing, however, laser processing normally occurs in air and is more flexible to manipulate using lenses and/or mirrors instead of magnetic coils. There are numerous examples of laser materials processing in industry to date. They range from the drilling of vanes and blades of jet engines, to the laser welding of the recuperators for the Abrams M1A1 Army main battle tank (11) (Figure 2) using low power lasers, to the

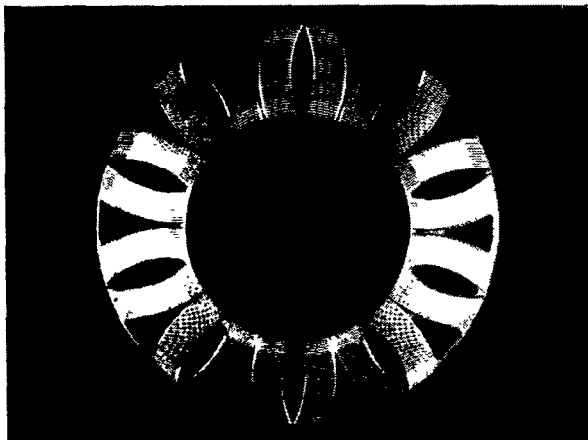


Figure 2.
Abrams AGT-1500 recuperator plate that is laser welded. Laser welds join plates along the ID's of the "footballs" and "triangles". Material is Inconel 615; 0.0081" thick.

welding of locomotive engine components, and the cladding of aircraft carrier catapult components with multi-kilo Watt

lasers. Lasers have been used in these applications because the low heat input of the process results in minimal amounts of distortion and small Heat Affected Zone (HAZ's).

Most industrial gaseous lasers are CO₂ lasers. This type of laser produces a beam of light at 10.6 microns at power levels from tenths of a Watt to 25 kilowatts. It can be used for welding or cutting on circuit board components at low power levels or for the welding of 12.7 mm thick steel plates using 10 kilowatts of power. The beam is delivered from the laser to the work piece using a series of mirrors and/or lenses in a beam duct. An example of a complex beam delivery system is the Laser Articulating Robotic System (8) (LARS) (Figure 3). Because of the high



Figure 3.
Laser Articulating Robotic System (LARS)

precision of the beam delivery, the LARS and similar systems (8, 9) are very complicated and expensive. limited the use of CO₂ lasers to assembly lines and work stations.

Some efforts have been made to use CO₂ lasers for in-situ operations. An example of this is the use of a low power (less than 1 kW) CO₂ laser to make heat exchanger repair welds (10). The system used a complex robot and "smart", self aligning mirrors to deliver the laser beam to the work piece.

The solid state laser has not changed dramatically since the first ruby lasers of the 60's. Today's industrial solid state lasers primarily use crystals of yttrium, aluminum, and garnet (YAG) or this combination doped with small amounts of neodymium, forming Nd:YAG glass (1). Most of these lasers are powered by flash/quartz lamps and have an average maximum output of 600 watts. In the past, these lasers have been used primarily for drilling and cutting in a pulse mode operation. An advantage that

the Nd:YAG laser has over the CO₂ laser is that its beam can be delivered through a flexible fiber optics cable. This allows for more flexible work stations and the possible use of conventional robots.

The Navy MANTECH office is funding a research program with the goal of developing, qualifying, and demonstrating a laser cladding process that is targeted for the refurbishment of submarine components which require hardfacing and corrosion protection. The laser cladding operation consists of depositing a powder directly in front of the laser beam which is at or near focus. The laser beam is oscillated perpendicular to the travel direction melting the powder and a minimal amount of base plate material (Figure 4). This results in a minimal amount of distortion due to thermal

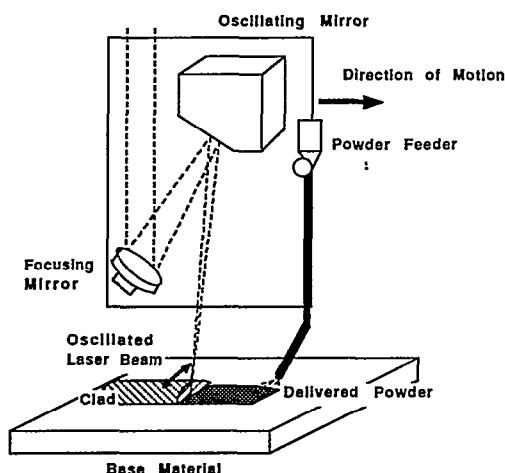


Figure 4.
Diagram of laser cladding system used with the high powered CO₂ laser.

gradients. Also, because the heat input is minimal, the molten pool solidifies rapidly with little or no segregation. The result is low dilution clad with minimum distortion.

Laser cladding procedures have been developed for a number of material combinations. The Navy MANTECH program has concentrated on cobalt/tungsten alloys (e.g., Stellite 6) for hardfacing material on a number of stainless and low carbon steels. The program is also in the process of developing laser procedures for the corrosion cladding of nickel-copper (e.g., Monel), nickel-chrome (e.g., Inconel 625), and nickel-chrome-molybdenum-tungsten (e.g., C-276) on HY- and HSLA- 80 steel alloys. This development work is being accomplished using a 14 kW CO₂ laser. The goal is to develop, qualify, demonstrate, and transfer the technology for the laser cladding of submarine components. The

targeted components, such as main steam and sea water valves, can be removed for this operation.

To date, the Navy MANTECH CO₂ laser cladding program has been very successful. Laser parameters have been developed and optimized for the cobalt-tungsten hardfacing material on 316L and 416 stainless steels and 4140 and DH-36 carbon steels. Metallurgical specimens have been made of the clads to measure the amount of dilution (Figure 5),

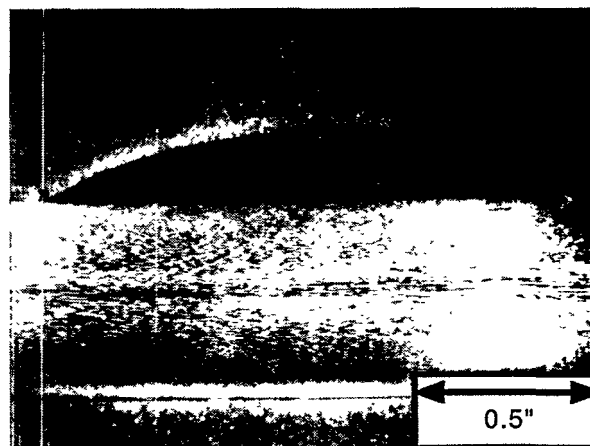
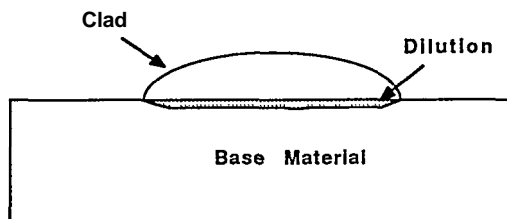


Figure 5.
(Top) Diagram of laser clad showing the base material, clad, and dilution material. (Bottom) Photo-macrograph of laser clad with Stellite 6 on 316 stainless steel.

evaluate the interface between the clad and the base materials (Figure 6), and to determine the microhardness of the HAZ and clad (Figures 7-9). Special "donut" shaped specimens were clad to determine the crack sensitivity of the process (Figures 10-12). Using optimized parameters, qualification clads have been produced and evaluated according to MIL-STD-248C. All of the clads have been made with no preheat to the substrate.

The high powered CO₂ laser cladding development program was well suited for a number of components that can be removed. But not all of the components that may require refurbishment can be easily removed and some components must be removed from the ship/sub through openings made in the hull of the vessel. This is extremely time consuming and

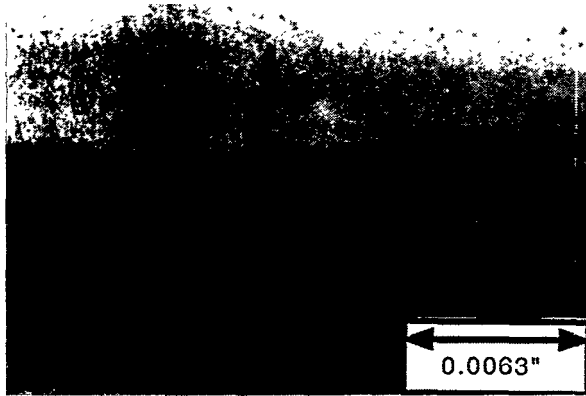


Figure 6.
Photo-micrograph of interface between Stellite 6 clad (top, white region) and 416 stainless steel (bottom, dark material).

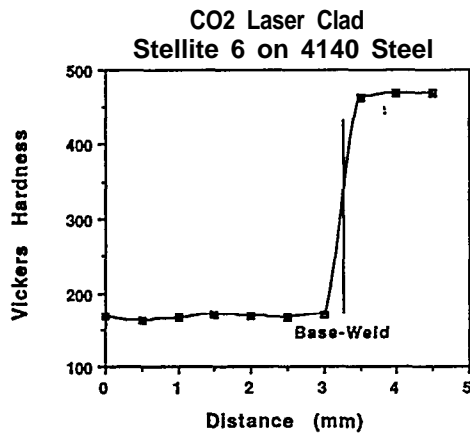


Figure 7.
Microhardness profile for laser clad of Stellite 6 on 316 stainless steel.

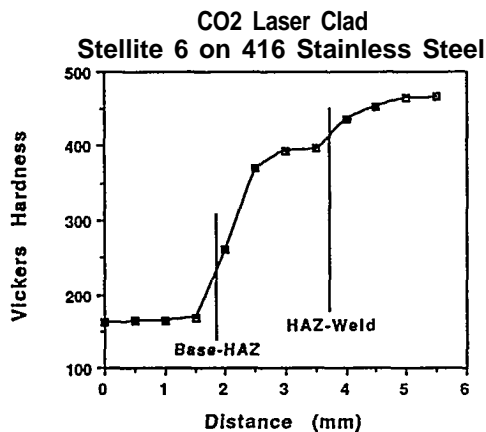


Figure 8.
Microhardness profile for laser clad of Stellite 6 on 416 stainless.

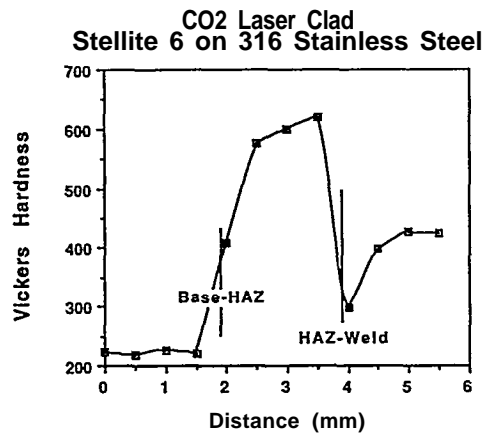


Figure 9.
Microhardness profile for laser clad of Stellite 6 on 4140.

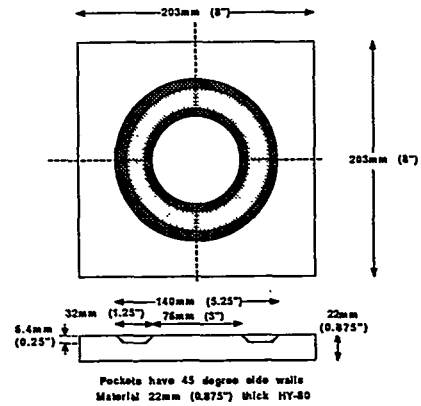


Figure 10.
Diagram of "Donut" test specimen that was used to determine the crack sensitivity of the laser cladding process.

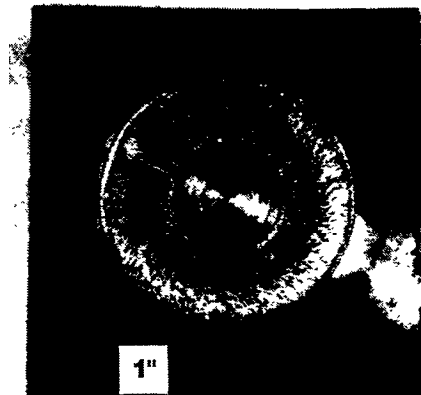


Figure 11.
Photograph of laser clad "Donut" specimen.

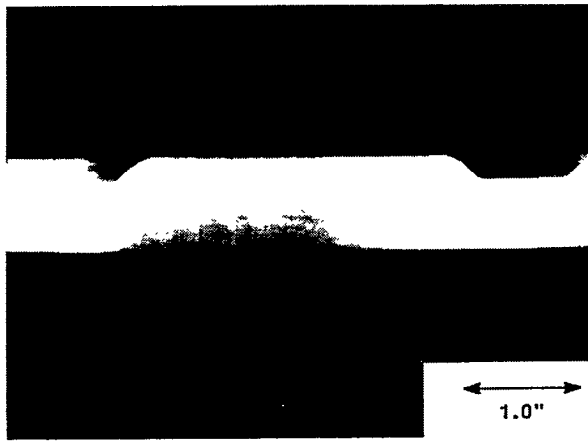


Figure 12.
Cross section of "Donut" specimen
showing the Stellite clad in the
pocket;

expensive. However, special tooling exists that allow for many of these components to be machined in-situ.

The second Navy MANTECH laser program has the objective of developing a method by which the laser cladding process can be accomplished on-board the ship. The use of such a laser system could minimize the dilution of the clad, decrease distortion, and eliminate the need for preheating and controlled cooling of the part. The program has centered on recent developments in the power output of Nd:YAG lasers and the use of fiber optics to deliver the Nd:YAG laser light. The goal of the program is to acquire advanced laser technology and develop laser processing techniques that can be qualified for the refurbishment of components in-situ.

As stated before, the maximum average power output for a single Nd:YAG crystal has been approximately 600 Watts of power. A number of companies in the USA and Japan have been developing ways to cost effectively combine the power from a number of different crystals at the work piece. One method is to independently deliver the beams to the work piece by fiber optics (1, 12). The beams can be delivered simultaneously or overlapped. The fiber optics also allow the beam to be redirected to a number of work stations as demanded. A second method of producing high powered Nd:YAG laser beams is to pass the laser beam through a number of crystals to form a single laser beam that has the power of the combined crystals. Some manufacturers have accomplished this using six standard crystals and the existing cooling methods (13). Power outputs averaging over 2 kW have been achieved for short periods in a pulse mode. Such high power levels have been

delivered through fiber optics as well. This system has been used to make field repair welds in heat exchangers in power plant facilities. In this case (14) a 2 kW Nd:YAG laser beam is delivered to the weld by fiber optics. This is an alternative to the use of the CO₂ laser based system mentioned earlier that used reflective optics to deliver the beam. However, the six crystal configuration used to produce the 2 kW in this system is very large, prone to alignment problems, and very expensive.

Recent advances have been made in the U.S. to modify the design of the multi-crystal laser system to make it more compact, reliable, and less expensive. The result has been a continuous wave laser using three crystals with a constant power output of 1.8 kW. This was achieved by decreasing the diameter of the Nd:YAG crystals and increasing the cooling water flow rate. Because this system is based on three crystals, it is rather compact and can be hardened for shipboard use. To deliver the laser beam to the work piece, the laser beam can be directed into a flexible, hardened fiber optic cable. There is combined power loss from the entering and exiting of the fiber optic cable of approximately 10%. The loss per unit length of cable is dependent on the quality of the fiber and the amount of bend and torque placed on the fiber. However, the 10% loss from the ends represents the majority of the power loss. At the work piece end of the fiber optic cable, a set of lenses refocus the laser beam for processing.

The results from the preliminary process development stage for the program indicate that the Nd:YAG can successfully be used to make clads. To date, a series of single and multiple layer laser clads of various material combinations have been successfully made with the 1800 Watt Nd:YAG system. These include cobalt-tungsten on 416 and 316 stainless steels and HY-80 and 4140 carbon steels (Figures 13 & 14). The clads have very low dilution rates as was the case for the high powered CO₂ laser clads and very shallow HAZ's in the base materials. The microhardness values were very similar to those obtained from the CO₂ laser cladding operation (Figures 15-17). Clads have also been made on previous laser passes. Minor imperfections must be corrected such as inclusions or pores in the overlap areas of the clads. A similar problem occurred in the CO₂ cladding but was corrected through modifications in the powder and power distribution.

The microhardness results from the Nd:YAG clads are very comparable to those of the high powered CO₂ clads. There appears to be minimal or no softening of the previous HAZ or clad regions.

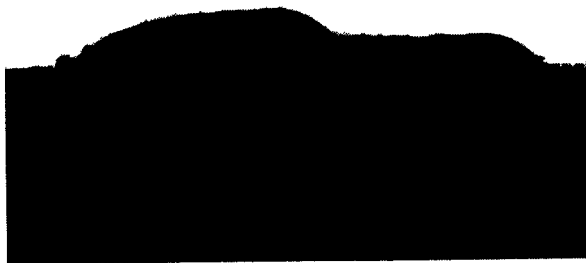


Figure 13.
Nd:YAG laser clad of Stellite 6 on
316 stainless steel.



Figure 14.
Nd:YAG laser clad of Stellite 6 on
416 stainless steel.

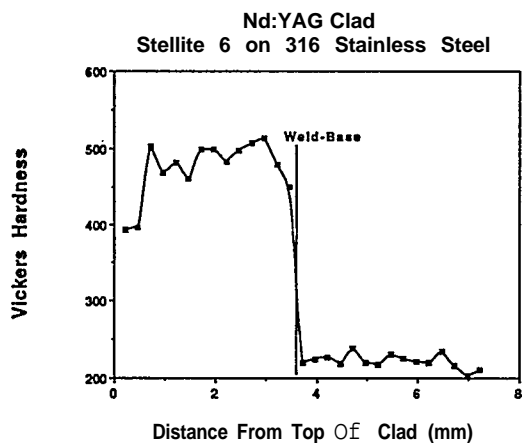


Figure 15.
Microhardness profile for Nd:YAG
laser clad of Stellite 6 on 316
stainless steel.

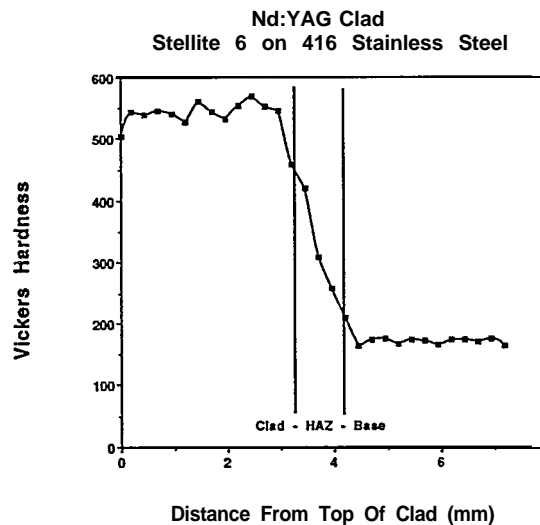


Figure 16.
Microhardness profile for Nd:YAG
laser clad of Stellite 6 on 416
stainless steel.

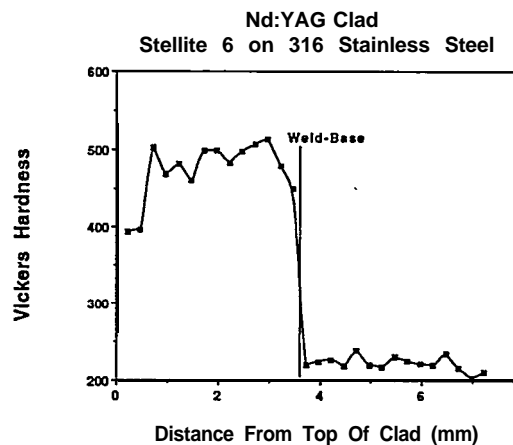


Figure 17.
Microhardness profile for Nd:YAG
laser clad of Stellite 6 on 4140
carbon steel.

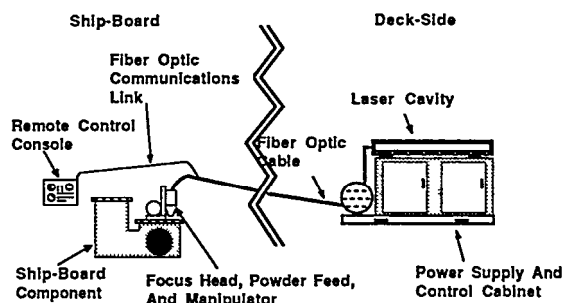


Figure 18.
Diagram of portable Nd:YAG laser
system.

All of the results to date have been accomplished in the simplest configuration using standard optics. The cladding has been accomplished in the "down-hand" position using gravity fed powder. Final application for the process will require that out-of-position processing methods be developed. The laser beam used was defocused (not at minimal spot size) which does not give an optimized power distribution during laser cladding. An oscillated and/or linear power distribution of the laser beam is better suited for cladding and is planned for later stages in the program.

The final stage of the Nd:YAG laser materials processing program will be the deployment of a portable laser system to the shipyard. The entire system--laser, chiller, and fiber optics--will be hardened for use on the water front (Figure 18). The planned procedure for utilization of the portable laser system in the shipyard is to position the laser and chiller on the dock or on deck. The fiber optics, laser processing head, and control panel will be passed through hatches and openings to the part that is being processed. The processing head will be attached to a manipulator and the area secured for operation. The manipulator can take the form of a simple linear motion device, modified portable machining equipment, or a small robotic system. The operator will control the laser and the processing through a communication box. The method for delivery of the cladding material has not been finalized. It may take the form of pre-placed powder, compacted powder, sprayed powder or solid inserts.

Future work is already being planned for the fiber optic Nd:YAG laser system. The development of parameters and procedures for laser cutting and welding is planned. A higher powered laser system, at the 2.4 kW level, is under development and is to be bench tested in late FY-91.

SUMMARY AND CONCLUSIONS

There have been a number of successes in the development of a laser cladding system that utilizes a fiber optic delivery system. Some of these accomplishments have been achieved as part of the CO₂ laser cladding program, however, many of the lessons learned there will be applicable to the Nd:YAG laser system. Listed below are a number of the accomplishments to date.

- 1) Parametric studies have been conducted using high power (14 kW) CO₂ lasers and Nd:YAG lasers for a variety of hardfacing/corrosion clad substrate combinations.

- 2) Both CO₂ and Nd:YAG laser clads have been found to have very low dilution rates (<10%). For hardfacing materials, this has resulted in high surface hardness values.
- 3) Both CO₂ and Nd:YAG laser clads have been made with no preheating of the substrate.
- 4) Qualification clads (MIL-STD-248C) have been accomplished with a high powered CO₂ laser for a number of hardfacing/substrate material combinations.
- 5) A portable laser system with fiber optic delivery system is scheduled for delivery for process development by mid FY-91 and with a demonstration in early FY-92.

Based on the rate of success to date, the technology transfer and implementation of the laser cladding process will occur rapidly. This will occur on two fronts; the application of the high power CO₂ laser for the initial cladding of new components and the refurbishment of worn on's that can be easily removed from a structure. The second front will be in the area of in-situ laser processing and machining for the refurbishment of parts that can not be economically moved and/or refurbished by conventional processing.

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Areal Coverage Using Friction Surfacing

IVB-2

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ABSTRACT

Areal coatings of 304 and 316 marine grade stainless steel were made on flat mild steel substrates using a low-pressure friction surfacing technique and various deposition configurations. The maximum through-thickness tensile bond strength obtained for such coatings was 890MPa (1.3×10^5 psi). Gaps and/or cracks between strips of deposited material were not eliminated completely during the manufacture of these coatings. Consequently, the overlay coatings described in this paper which were made using a range of overlapping and non-overlapping deposition configurations, are primarily suitable for applications in non-corrosive environments.

INTRODUCTION

Friction surfacing is a variation of a friction joining technique which first patented by Klopstock and Neelands^[1] in 1941. During the 1980's this technique experienced a resurgence of interest[2,3,4,5,6 and 7]. In

friction surfacing a metallic bar is rotated and forced axially against a metallic substrate (Figure 1a). The heat generated by the bar rubbing against the substrate causes the end of the bar to soften and plasticise (Figure 1b). The substrate is traversed across the end of the bar transferring a strip of the bar material onto the substrate (Figure 1c).

The width, thickness and quality of the adhesive bond between the deposited strip of material and the substrate are dependent on the process parameters and the materials used^[7]. Typically for deposits made at low frictional pressures^[7and8] the width of the deposited material is 60-90% of the original bar diameter and the deposit can be 1-3mm (0.04 - 0.12 in) thick. Results from through thickness tensile tests indicate that bond strengths approaching the ultimate yield strength of the deposited material can be achieved by optimization of the process conditions^[8].

Areal coverage of a substrate can be achieved by the deposition of several adjacent strips of the consumable bar material. For many applications such as protection of components from abrasion

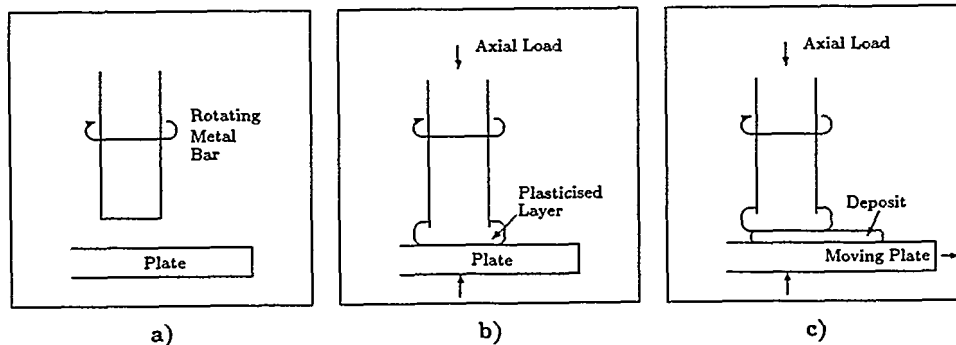


Figure 1: Schematic representation of friction surfacing process.

- Rotating metal bar brought to required speed above metal plate.
- Rotating bar loaded axially against plate until plasticized layer forms at end of bar.
- Metal plate traversed across rotating bar leaving behind a well bonded deposit.

damage it may not matter if there are small gaps between these overlay strips. However for other applications where the integrity of the overlay is important it is necessary to avoid such voids.

Using a low-pressure friction surfacing technique^[7] developed at the Materials Research Laboratory (MRL) we have looked at two methods of areal coverage, one which attempts to reduce/avoid such gaps and one that does not. Emphasis in this investigation was placed on methods which required minimal surface preparation during the overlay coating procedure. Such methods are clearly advantageous in industrial applications of friction surfacing as they reduce both the total cost and process time required. Single and multiple coatings of marine grade 304 and 316 stainless steel, laid in various configurations, were produced and the through thickness tensile bond strengths were determined.

MARITIME/NAVAL APPLICATIONS OF FRICTION SURFACING

It is envisioned that friction surfacing will have applications in the five general areas listed below. Note however that additional research and development is required before some of these applications become commercially viable.

Reclamation. Components which can be reclaimed using friction surfacing include camshafts, crankshafts and propeller shafts used in a maritime environment. FRICTECH, a British company offers such services on a commercial basis. Cost savings can be realised by a combination of increased component lifetimes and reduced inventories. In addition, using other developments, it may be possible to refurbish propeller shafts in situ, thus reducing significantly the time required in dry dock facilities during a major refit. This would be particularly applicable to submarine refits.

Hardfacing. This capability has been demonstrated by the deposition of a hard tool steel onto aluminium substrates. This procedure has many uses such as the production of dual hardness armour. An example of its primary use on wear surfaces could be to build up shafts at journal sites to provide a wear resistant deposit.

Corrosion. Corrosion protection could be achieved at reduced cost by using the friction surfacing techniques to bond an expensive corrosion resistant steel surface layer onto a cheaper steel

substrate. This approach is well suited for components used in marine environments. In particular friction surfacing may be a competitor for chromium plating of marine components in situations where size, shape or hydrogen embrittlement is a problem.

Joining. Metal plates could be joined during manufacture using a friction surfacing technique. As the processes involved in friction surfacing are solid state rather than fusion the metal plates do not need to be pre-heated as in many welding operations. The heat affected zone due to the friction surfacing procedure is small and therefore the previous heat treatment of the component is only minimally affected.

Repair. Minor damage to steel plates could be repaired in the field using portable friction surfacing equipment. Cracks can be sealed and strength provided to a steel plate by friction surfacing an overlay deposit along the crack. Alternatively, hole repair and crack patching could be achieved by placing a metal section over the hole/crack and then depositing an overlay coating between the plate and the metal section. Friction surfacing does not require the use of bottled gases as in welding and is therefore not limited by the availability of such gases. Preliminary research indicates that friction surfacing will work under water^[7]. Consequently it is particularly suitable for maritime/naval applications including submarine field repairs.

EXPERIMENTAL METHOD

Friction Surfacing Equipment

A schematic representation of the equipment used for low-pressure friction surfacing is shown in Figure 2. A pneumatic ram and substrate holder were added to a standard Heidenreich and Harbeck VDF research lathe. The maximum axial load permissible with the standard lathe headstock bearing system is 4.9kN. Additional details can be found in Jenkins and Doyle^[7].

The substrate holder was attached to the cross feed mechanism of the lathe as shown in Figure 2. During the deposition process a free sliding metal plate with an attached teflon sheet, located at the rear of the substrate holder, permitted the load from the pneumatic ram to be applied colinearly with the rotation axis of the consumable bar as the cross feed mechanism was used to translate the substrate. Metal plates with maximum dimensions of 300mm x 140mm x 20mm (12" x 5.5" x 0.8") were attached to the substrate holder using two bolts.

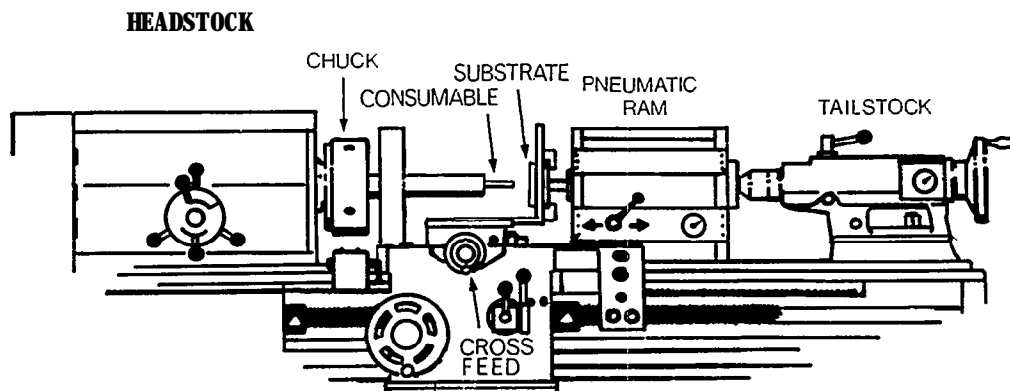


Figure 2.
Schematic representation of equipment used for friction surfacing.

Sample Preparation

Consumables were made from 19mm (3/4") diameter 304 and 316 stainless steel bar. The bars were cut into 105mm (4") lengths and a 45mm (1.8") long, 19mm (3/4") BSW thread was cut into one end of each consumable. The consumables were screwed into a holder which was designed to be clamped in the lathe chuck.

Substrates were prepared in two sizes from 10mm (0.4") thick bright mild steel plate. These comprised of 230mm x 75mm (9" x 3") and 140mm x 140mm (5½" x 5½") sections which were milled to a surface roughness which ranged between a centre line average of 0.7µm and 1.5µm. Consumables and substrates were cleaned with ethanol immediately before use.

Experimental procedure

All deposits were made at room temperature and pressure in an ambient air environment. Prior to commencing the surfacing process the desired axial load was obtained by adjustment of the

pressure relief valve on the pneumatic ram while the consumable and substrate were stationary and in contact. With the consumable and substrate separated the lathe was brought to the required rotational speed. Subsequently the pneumatic ram was engaged at the pre-set load forcing the substrate into contact with the rotating consumable. A dwell time between 5 and 7 seconds was sufficient for the region near the end of the consumable to plasticise and glow white hot. At this time the cross feed mechanism of the lathe was engaged and the substrate was translated across the face of the rotating consumable leaving behind a strip of consumable material deposited on the substrate. When the deposited strip was of the desired length, the pneumatic ram was disengaged which also withdrew the substrate from contact with the consumable.

The process conditions required to produce 304 and 316 stainless steel deposits of uniform width at the lowest possible frictional pressure are listed in Table I. Deposits were made with the substrate normal inclined at several angles 0, 5, 10, and 15° to the consumable rotation axis (see Figure 3). Those deposits made with $n = 0$ were

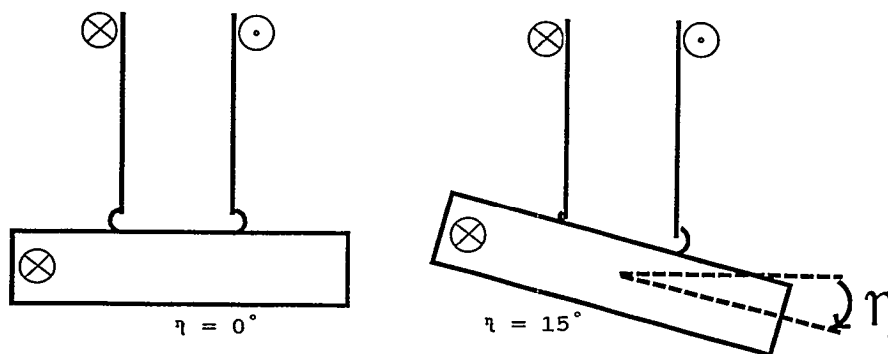


Figure 3.
Geometric relationships adopted for friction surfacing. The symbol, \otimes , represents movement in a direction into the plane of the paper while, \odot , represents movement in a direction out of the paper.

found to have a cross sectional shape which resembled a wedge. It was expected that by overlapping such wedge shape strips a full areal coverage could be built up without guarding against poor cohesion between the different deposits.

Transverse cross sections were prepared from 304 and 316 deposits for optical micrographs. These were polished using standard metallographical techniques and were etched with a 2% nital solution.

Through-Thickness Tensile Test

Through-thickness bond strength is defined as the tensile adhesive stress required to separate a deposit from the substrate.

The through-thickness tensile test specimens used in this investigation to evaluate the bond strength were made by friction welding a stud, of same material, to the surface of the deposited coating (see Figure 4a). A good bond was obtained between the friction welded stud and the deposit by grinding smooth the surface of the deposit at the position where the stud was to be attached. A segment of the substrate containing the friction welded

stud was cut from the remaining substrate. Material was then removed from the stud, deposit and substrate by machining (see Figure 4b). The through-thickness tensile test specimen had a gauge length of 15mm and a gauge diameter of 5mm. The specimens were loaded to failure in an Amsler universal testing machine and the maximum load recorded.

RESULTS

The deposition control parameters were selected in order to obtain the lowest axial load which produced uniform deposits at an inclination angle $n = 0^\circ$. These conditions for 304 and 316 stainless steel are listed in Table I.

A cross sectional view of 304 stainless steel deposited on a mild steel substrate at n angles of 5, 10, and 15° is shown in Figure 5. Note that the depth of the heat affected zones beneath each deposit is approximately equivalent to the maximum thickness of the deposit.

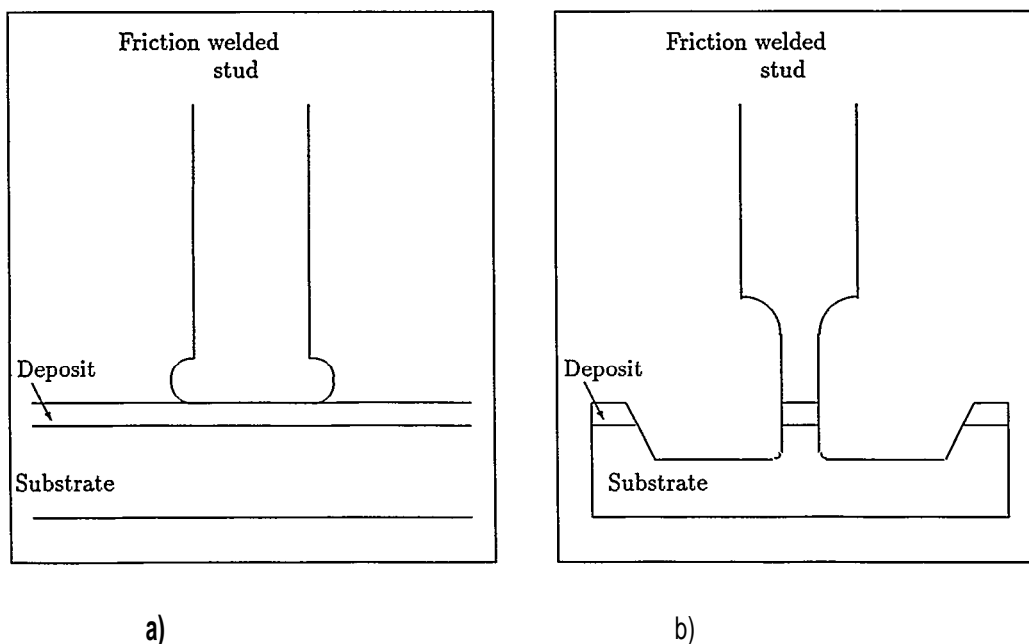


Figure 4.
Manufacture of through-thickness tensile test specimens.
a) Attachment of a friction welded stud to a deposit material bonded to a substrate by friction surfacing.
b) Remove of stud, deposit and substrate material by machining to produce tensile test specimens.

Table I. Friction surfacing process conditions for uniform deposits at a frictional pressure of 10.6 MPa.

		Material	
		304	316
Inclination Angle	Consumable Rotation (rpm)	1400	1400
	Cross-Feed Translation (rpm)	497	497
0°	Average Thickness (mm)	1.3	1.0
	Average Width (mm)	14	12
5°	Maximum Wedge thickness (mm)	1.5	-
	Average Width (mm)	12	-
10°	Maximum Wedge thickness (mm)	2.5	
	Average Width (mm)	14	
15°	Maximum Wedge thickness (mm)	4.0	
	Average Width (mm)	17	

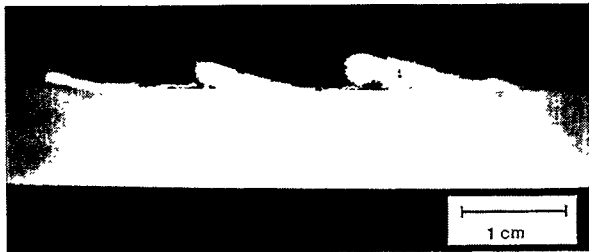


Figure 5. Cross sectional view of 304 stainless steel deposits made at angles of 5, 10 and 15°. Note the heat affected zone extending from the apex of each wedge-like deposit.

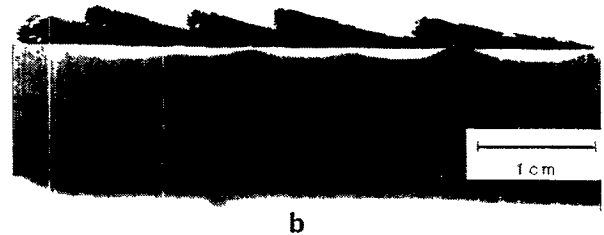


Figure 7. Series of overlapping 304 stainless steel deposits made at an inclination angle of 15°.

- Plan view of overlapping deposits which were started from left hand edge of figure. Apex of each wedgelike deposit is closest to bottom of figure.
- Transverse cross section through a position near the start of the coating shown in Figure 7a. Note the overlap of each heat affected zone located below individual deposits.

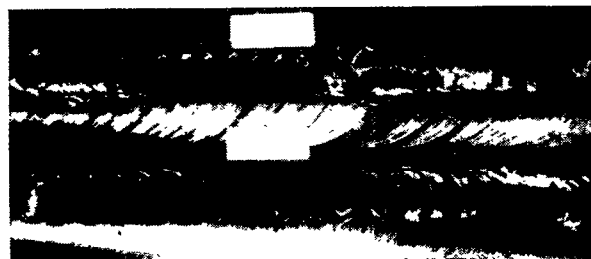


Figure 6. Deposits of 316 stainless steel made at angles of 5° (top) and 10° (bottom). Note non uniform width of deposits.

Measurements for the thickness and widths of 316 stainless steel deposits made at angles of 5° and 10° are not given in Table I. These deposits (typical examples shown in Figure 6) were not considered sufficiently uniform to be useful for area coverage.

The 304 stainless steel coatings at an inclination angle $\alpha = 15^\circ$ produced the most uniform of the $\alpha = 0^\circ$ deposits listed in Table I. An example of overlapping 304 deposits made with an angle of inclination of $\alpha = 15^\circ$ is shown in Figure 7a. In Figure 7a all deposits were started from the left hand end of the substrate and the thin part of the wedge for each deposit is closest to the bottom of the figure. A cross section made near the start of these overlapping deposits is shown in Figure 7b. The extent of the overlap between deposits shown in Figure 7b ranged from 20% to 65%. However overlaps of up to 80% were obtained for some samples (see also part of the first deposit strip in Figure 7a).

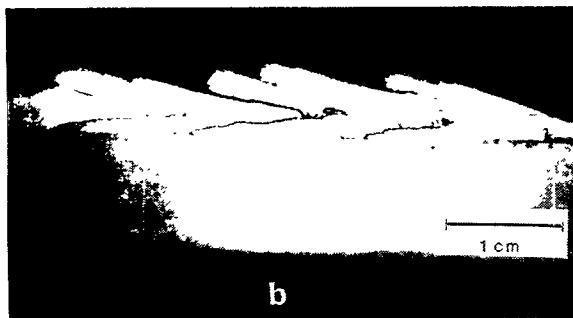


Figure 8.
Multiple overlay coating of 304 stainless steel made at an α angle of 15° .

- a) Four overlapping deposits are partially covered by a second series of five overlapping deposits made in a direction orthogonal to the original coating direction.
- b) Cross sectional view of the sample shown in Figure 8a, taken in a plane which bisected the two orthogonal traverse directions.

In Figure 8a can be seen a multiple overlay coating of 304 stainless steel deposited with an inclination angle of 15° . The first coating consisted of a series of four overlapping deposits. This coating was partially covered with the second series of five overlapping deposits which were deposited with a traverse direction orthogonal to the original coating direction. A cross sectional view is shown in Figure 8b of this multiple overlay coating, taken in a plane which bisected the two coating traverse directions of Figure 8a.

A cross sectional view is shown in Figure 9a of a coating produced with an alternative approach for areal coverage of a flat substrate. The coating was made using an inclination angle of 0° and depositing strips of 316 stainless steel with a gap of slightly less than the width of one deposit between the strips. A second set of strips of 316 material were deposited in these gaps. This method produced coatings which were much more uniform in thickness than the coatings made at non zero angles of inclination. On completion of such a coating no obvious gaps between the individual deposits were visible at the surface to the naked eye. However hairline gaps between the deposits can



Figure 9.
Areal coating of 316 stainless steel made at an α angle of 15° .
a) Cross sectional view.
b) Magnified cross sectional view of sample shown in Figure 9a.

Deposition Condition	Bond Strength (MPa)	
	304 deposits	316 deposits
$\alpha := 0^\circ$, single pass	630	890
$\alpha := 15^\circ$, single pass	702	827
$\alpha := 15^\circ$, overlay, dual pass no grinding	*	-
$\alpha := 15^\circ$, overlay, dual pass with grinding	334	-

Table II. Through-thickness tensile bond strengths near the start of deposits made using the process conditions listed in Table I. Note (-) indicates that the material was not suitable for overlay deposits and (*) indicates that the specimen broke while being machined into a tensile specimen.

clearly be seen in the magnified, transverse cross section shown in Figure 9b.

Through-thickness tensile bond strengths were measured near the start of several typical deposits. Representative results for the bond strengths of such 304 and 316 stainless steel deposits near the start of the deposit are listed in Table II.

During the tensile tests all specimens fractured at or across the deposit substrate interface. No specimen failed at the deposit stud interface.

DISCUSSION

An important requirement for many applications is an areal coating which is devoid of gaps or cracks. Many manufactured components operate in hostile environments and if such gaps/cracks exist in a friction surfaced coating then it is likely that the coating may eventually debond/fail through the action of corrosion at these sites. Consequently a number of different equipment configurations, as described in the previous section, were examined in an attempt to reduce or eliminate these potential failure sites.

The equipment configurations can be divided into two categories, one which involves deposition with a zero angle of inclination and the other with a non zero angle of inclination.

Non Zero Angle of Inclination Coatings

An important feature of the friction surfacing process is the disruption of the interface between the consumable bar and the substrate. This disruption may lead to simple mechanical keying of the deposit or, when the conditions lead to the removal of surface contaminants,

to full metallurgical bonding.

The standard friction surfacing process can be modified by utilizing a non zero angle of inclination and overlapping the resultant strips of wedgelike deposits. This procedure disrupts simultaneously the consumable to substrate and consumable to (previously layed consumable) strip interfaces, hopefully eliminating hairline gaps between adjacent strips of deposit material.

The angle of inclination for 304 stainless steel used in area coverage deposits was selected after examination of a series of trial deposits made at angles of 5, 10 and 15 (see Figure 5). The width and thickness (at the thickest part of the wedge) of each deposit was uniform. In addition the heat affected zone in the substrate material was located towards the apex of the wedge (see Figure 5) for all deposits. It can be inferred from this characteristic that the adhesion between the deposit and substrate decreases as distance from the apex increases. Therefore if the angle of inclination is increased too much the part of the deposit away from the apex will become poorly bonded. Note that the thickest regions of each wedge (Figure 5) are not bonded to substrate.

The maximum inclination angle permitted for good bonding is material dependent and probably sensitive to the reactivity of the consumable to atmospheric constituents. Thus it has been found that good deposits of 304 stainless steel can be made at inclinations up to 15°, while an angle as small as 5° produces unsuitable deposits of 316 stainless steel.

It is clear, from Figure 5 and Table I, that the maximum amount of material was deposited on the substrate for an inclination angle of 15°. This bulkier deposit was advantageous since

the sawtooth cross section produced from partially overlaying a series of such deposits (see Figure 7b) could be removed by grinding to produce a flat coating which was 1-2mm thick. Such a procedure also removes the non bonded region of the deposit at the thick end of the wedge. Consequently, all 304 stainless steel coatings were made at an inclination angle of 15". This bulkier deposit was advantageous since the sawtooth cross section produced by partially overlaying a series of such deposits (see Figure 7b) could be removed by grinding to produce a flat coating which was 1-2 mm (0.04-0.08") thick. Such a procedure also removes the non bonded region of the deposit at the thick end of the wedge. Consequently, all 304 stainless steel coatings were made at an inclination angle of 15".

All 316 stainless steel deposits made at non zero angles of inclination had a non uniform width (see Figure 6) and were therefore considered to be unsuitable for this type areal coverage. However the through-thickness tensile bond strength of 827MPa (1.2×10^5 psi) for a single strip of 316 deposited with an inclination angle of 15" compared very favourably with the bond strength of 890 MPa (1.3×10^5 psi) for 316 deposited with an inclination angle of 0° (Table II). The bond strength for 304 stainless steel (Table II) increased from 630 MPa (9.1×10^4 psi) to 702 MPa (1×10^5 psi) as increased from 0 to 15" respectively. This small increase of bond strength provides further evidence that 304 stainless steel is suitable for use in areal coverage applications.

Tensile test specimens made from a 304 stainless steel coating similar to that shown in Figure 7, deposited using an inclination angle of 15" and an 80% overlap between individual strips of material broke at the interface between the overlapping to underlying deposits during machining. However the bond strength increased to 334MPa (Table II) for coatings made by grinding the surface of each deposited strip prior to friction surfacing the next overlapping strip of material. All tensile test specimens were made in regions devoid of cracks and gaps. Consequently the through-thickness tensile bond strengths listed in Table II are indicative of the bonds strengths available from coatings which are both uniform and homogenous.

It can be seen from Figure 7b that gaps occur between the overlapping 304 stainless steel deposits. These gaps are observed to be larger and often extend directly to the substrate material between deposits which have only a small degree of overlap. The gaps between deposits with greater than 40-50% overlap are intermittent and regions can

be observed where full metallurgical bonding occurs between the adjacent deposit strips (see Figure 7c). Deposits with an overlap of approximately 80% exhibit consistent metal to metal bonding not only at the deposit to substrate interface but also in the region near the apex of the deposit to deposit interface.

All 304 stainless steel deposits within the range of 20% to 80% overlap were well adhered to the substrate irrespective of whether gaps existed between adjacent deposit strips. Consequently such coatings produced without surface preparation between each deposit are suitable for applications in non corrosive environments. Coatings made by friction surfacing for use in corrosive environments require that the overlap between adjacent deposits is approximately 80% to minimise the formation of gaps. Alternately if a smaller overlap or additional bond strength is needed the surface of the deposit must be prepared (e.g. by grinding) prior to overlapping additional material.

5.2 Zero Angle of Inclination Coatings

Coatings of 304 and 316 stainless steel were made at an angle of 0° using the procedure described briefly in section 3. It can be seen from Table II that 316 deposits made in this configuration had a through-thickness tensile bond strength of 890MPa which was significantly better than the 630MPa achieved with comparative deposits of 304 stainless steel.

Although gaps between adjacent strips of deposited 316 material are not obvious to the naked eye (Figure 9a), they can be discerned clearly in the magnified image shown in Figure 9b. In addition there are cracks visible within some of the deposit strips shown in Figure 9b, caused by thermal stresses upon cooling of the deposit substrate combination. Clearly, such gaps and cracks which extend the entire thickness of the deposited coating preclude this type of coating being suitable for use in corrosive environments without further surface preparation. However this coating configuration using 316 stainless steel had the best bond strength between the deposit and substrate and is therefore acceptable for applications in non corrosive environments.

6.0 Conclusions

At low frictional pressures and with no surface preparation between overlapping deposits it was found that 304 stainless steel is suitable for

areal coverage using non zero inclination angles while 316 stainless steel is only suitable for deposits made with zero angles of inclination. However these areal deposits are suitable only for applications in non corrosive environments as the cracks/gaps between individual strips of deposited material are not eliminated in the manufacturing process.

Friction surfaced areal coatings for use in corrosive environments require that the surface of each deposited strip of material is prepared by a procedure such as grinding. Such preparation provides a smooth clean surface to which a subsequent deposit adheres without the formation of gaps or cracks which extend through the coating to the substrate surface. This additional surface preparation increases the costs of manufacturing such components.

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Recent MIT Research on Residual Stresses and Distortion in Welded Structures

IVB-3

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ABSTRACT

This paper presents a summary of recent efforts by the Welding Research Group at the Department of Ocean Engineering, M.I.T. The major thrust of the efforts has been to develop technologies of reducing residual stresses and distortion through in-process 'control. Part I discusses (a) reduction of longitudinal bending distortion of built-up beams, (b) reduction of radial distortion and residual stresses in girth-welded pipes, (c) reduction of forces acting on tack welds during butt welding, and (d) reduction of residual stresses and distortion in high-strength steel weldments. Part II presents a brief summary of other studies including (e) forming of steel plates by line heating with a high-power laser beam, (f) an intelligent system for flame straightening of panel structures, and (g) a knowledge-based system for minimizing out-of-plane distortion of welded panel structures.

INTRODUCTION

Residual stresses and distortion are major problems associated with welding fabrication of large, complex structures including ships, submarines, and offshore structures. Because a weldment is locally heated by the welding heat source, complex thermal stresses occur during welding, and residual stresses and distortion remain after welding is completed. These stresses and distortion have various

consequences, most of which are detrimental to the integrity of welded structures. Correcting unacceptable distortion is very expensive and in some cases impossible. Engineers in the shipbuilding industry will face severer problems with residual stresses and distortion in the years ahead, because:

- (a) We are using increasing amounts of thinner sections which tend to distort more,
- (b) We are using increasing amounts of aluminum alloys and other non-ferrous alloys which tend to cause more distortion problems,
- (c) Some structures such as deep diving submarines must be fabricated with increasingly more stringent tolerance for distortion, especially out-of-plane distortion.

The author believes that the best way of dealing with these problems is to develop technologies for controlling and reducing residual stresses and distortion during fabrication. The best method of accomplishing this is to utilize real-time controls during welding while non-elastic strains that cause these stresses and strains are being formed.

The Welding Research Group at the Department of Ocean Engineering of the Massachusetts Institute of Technology has (for many years) performed research on various subjects related to residual stresses and distortion in welded structures. The major thrust

of recent research efforts has been to advance the state-of-the-art of controlling and reducing residual stresses and distortion in weldments. Additional studies with other objectives also have been performed. This paper reviews these efforts in the following two parts:

- Part 1: In-process reduction and control of residual stresses and distortion in weldments
- Part 2: Summary of other research activities.

PART 1: IN-PROCESS REDUCTION AND CONTROL OF RESIDUAL STRESSES AND DISTORTION IN WELDMENTS

Basic Concept of In-Process Control of Residual Stresses and Distortion

The reason why real-time control is important for reducing residual stresses and distortion can be understood by studying mechanisms of their formation. Figure 1 shows schematically how a rectangular plate deforms when arc welding is performed along its upper longitudinal edge.

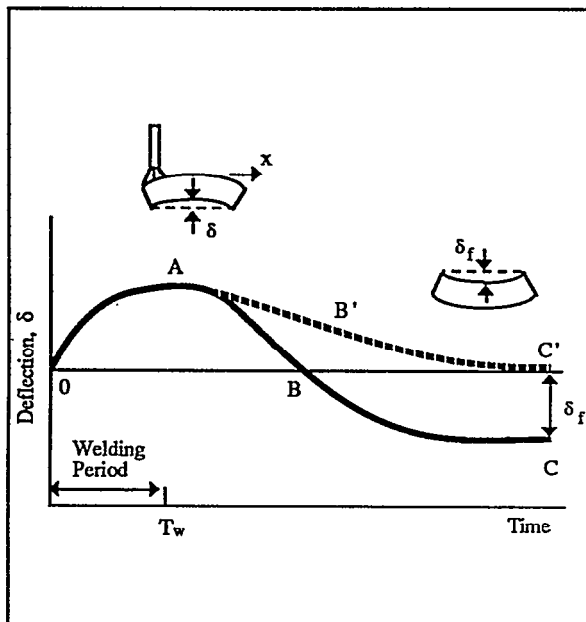


Figure 1 Transient Deformation of a Rectangular Plate During and After Welding

Since temperatures are higher in regions near the upper edge, these regions expand more than regions near the lower edge causing the upward movement of the center of the plate, δ , as shown by Curve OA. The most important stress component is the longitudinal stress, σ_x . Stresses in regions near the weld are compressive, because thermal expansions in these regions are restrained by the surrounding metals at lower temperatures. Since the temperatures of the regions near the weld are quite high and yield stresses of the material are low, compressive plastic strains are produced in these regions. When welding is completed and the plate starts to cool, it deforms in the opposite direction. If the material was completely elastic during the entire period of the heating and cooling cycle, the plate would deform as shown by Curve OAB'C' returning to its initial shape with no residual distortion. However, this does not happen during welding a real material, be it steel, aluminum, or titanium. As a result of the compressive plastic strains produced in regions near the upper edge, the plate continues to deform after passing its initial shape, as shown by Curve OABC, resulting in the negative final distortion, δ_f , when the plate cools down to its initial temperature.

The most effective way of reducing distortion is to control the formation of plastic strains produced in regions near the weld. The difficulty here is that the necessary control must be maintained during welding while the weldment undergoes complex changes of thermal stresses. In order to have correct and consistent controls, one must have the following capabilities:

- (1) Prediction capability. One must have a proper capability of predicting, by analysis, prior experiments, and/or experience, (a) how the weldment being studied deforms and (b) how to perform proper controls to change the distortion being considered.

- (2) Sensing capability. One must also have a proper device or devices for sensing if what should happen is actually happening.
- (3) Control capability. If one finds that what is actually happening is different from what is suppose to happen, it is important that he/she has capability of making necessary changes, in real-time if needed.

Efforts have been made to improve these capabilities.

Regarding prediction capability, a series of computer programs have been developed including (a) simple one-dimensional programs which analyze only the stress component parallel to the weld line or the longitudinal stress and (b) finite-element programs capable of analyzing more complex stress fields [1]. Although the one-dimensional programs can analyze only the longitudinal stress, they are fast and very economical to use. On the other hand, finite element programs are capable of analyzing stresses in more complex fields, but they tend to be slow and expensive to operate.

Regarding sensing capability, efforts have been made for improving techniques for measuring out-of-plane distortion. The following systems have been developed and used [2]:

- (a) A laser interferometer capable of non-contact measurement of a minute amount of distortion by using a bright-and-dark grid system generated in space by a light system produced by a low-power laser beam;
- (b) A laser vision system capable of non-contact measurement of relatively large amount of distortion by accurately measuring distances between the lower-powered laser source and measuring points; and
- (c) A mechanical system nicknamed “oc-

topus” capable of measuring radii of curvature in four directions around a measuring point by use of eight dial gages located along a circle surrounding the measuring point.

Regarding control capability, techniques involving alteration of heating patterns and application of additional forces were tried. Although uses of these techniques for controlling residual stresses and distortion in weldments have been tried for a number of years by many investigators, approaches taken in the past were primarily empirical or trial-and-error. The unique feature of the current effort. is the combination of control capabilities with prediction and sensing capabilities so that the effort becomes science rather than art.

The author recognizes that addition of other controls, either by changing thermal patterns and/or providing additional forces during manual welding, is unrealistic if not impossible. However, it should be possible to apply additional controls during automatic welding. In fact, it should be possible to develop a fixture that can apply needed controls during welding. Such a fixture may be called an “intelligent fixture.”

Various studies have been done in the area of in-process control of residual stresses and distortion using prediction, sensing and control capabilities described above. Following are the subject areas of four of these studies.

- Study 1: Reduction of longitudinal bending distortion of built-up beams,
- Study 2: Reduction of radial distortion and residual stresses in girth-welded pipes,
- Study 3: Reduction of forces acting on tack welds in a butt joint,
- Study 4: Reduction of residual stresses and distortion in weldments in high-strength steels.

Following are brief background discussions of the first two studies performed sometime ago. Then more detailed discussions are given on the last two studies which were performed more recently.

Reduction of Longitudinal Bending Distortion of Built-up Beams

Experimental and analytical studies were performed in the 1970's for reducing longitudinal bending distortion of built-up beams by a technique that is called "differential heating" [1]. The basic idea is to reduce distortion by joining plates with different (properly selected) initial temperatures. Serotta conducted a series of experiments to investigate how differential heating reduces the longitudinal distortion produced during welding fabrication of a T-beam in 5052-H33 aluminum alloy [3]. A web plate, 48"x6"x0.5" (1,220x 152x 12.7 mm), was fillet welded to a flange plate, 48" x 4" x 0.5" (1,220 x 102 x 12.7 mm) by gas metal arc welding. Nishida analyzed the experimental results obtained by Serotta by using the one-dimensional computer program developed at M.I.T. [4]. Figure 2-(a) shows changes of deflections during and after welding fabrication of beams. Analytical results are shown in solid lines, while experimental results are shown in broken lines. The final distortion after the specimen cooled down completely was negative (see the sketch in the lower part of the figure) when initial temperatures of the web and the flange were the same. When the differential heating was used, on the other hand, the final distortion changed to positive (see the sketch in the upper part of the figure).

Figure 2-(b) shows how the preheating temperature of the web affected the final distortion of a built-up beam. The discrepancies between the experimental data and the analytical results were significant when the web was heated to relatively high temperatures. It is believed that the experimental data for high preheating temperatures is not accurate, since

the temperature differential is reduced by conduction. The figure shows that the zero distortion can be achieved by heating the web to around 120°F (49°C). When welding is done in more than one pass, the best technique is to produce a slightly negative distortion after the first welding pass by using a higher preheating temperature so that the distortion after completing the final pass will be close to zero.

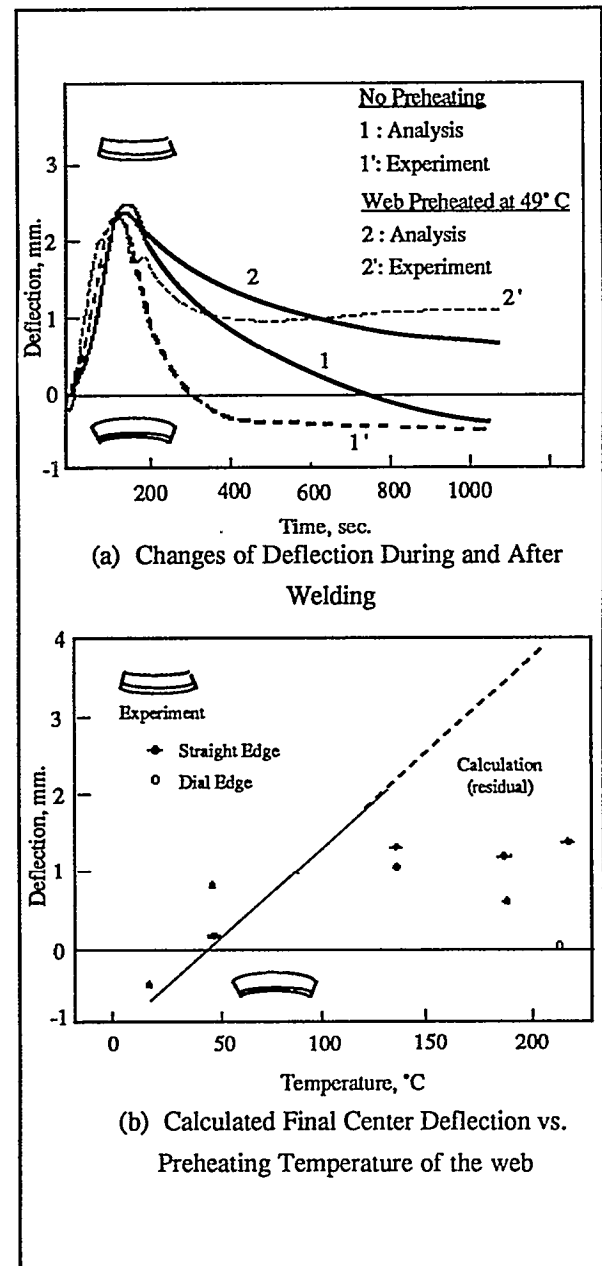


Figure 2 Reduction of Longitudinal Bending Distortion Due to Welding Fabrication of an I-Beam by Use of the Differential Heating Technique

Reduction of Radial Distortion and Residual Stresses in Girth-Welded Pipes

Studies have been carried out to develop techniques for reducing radial distortion and residual stresses produced by girth-welding of pipes.

In the first study performed by DeBiccari, a turnbuckle was used to provide an additional restraint to a specimen, as shown in the upper right corner of Figure 3 [5]. Forces generated by the turnbuckle were transmitted to the specimen through two semi-circular shoes so that various locations along the girth were subjected to varying degrees of restraint. The turnbuckle was instrumented with strain gages in order to monitor changes of restraining forces during welding. The inner diameter of the pipe was 12 inches (305 mm), and the wall thickness was 5/16 inch (8 mm). Figure 3 shows relationships between the distance (in the direction parallel to the longitudinal axis of the pipe) from the weldedge (the borderline between the weld metal and the base metal) and values of radial contraction measured at four locations along the girth: $\theta = 0, 30, 60$, and 90 degrees. Shown in the thick line is the radial contraction obtained on a specimen welded without using the turnbuckle restraining system. The results may be summarized as follows:

- (1) Distortion Shape The amount of the radial contraction is the largest near the weld, and it greatly decreases as the longitudinal distance from the weld increases, and
- (2) Effectiveness of Additional Restraint The additional restraint provided by the turnbuckle system decreases the radial contraction very effectively. As the angle θ increases, the degree of restraint by the shoe decreases; therefore, the radial contraction increases. DeBiccari also found that restraining forces measured by strain gages mounted on the

turnbuckle decreased momentarily when the welding arc passed areas where the turnbuckle touched the pipe ($\theta = 0$ and 180 degrees). These reductions of restraining forces are believed to be caused by the expansion of the pipe due to the welding heat. He also found that residual stresses measured on the restrained pipe were generally lower than those obtained on the pipe with no additional restraint.

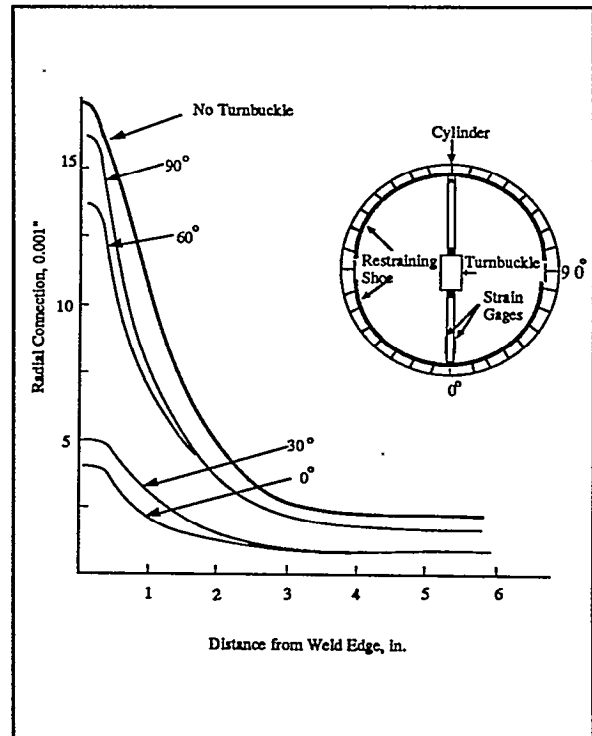


Figure 3 Reduction of Residual Distortion of a Girth Welded Steel Pipe by Application of Internal Pressure Using an Instrumented Turnbuckle System

In the second study performed by Barnes, a restraining system using six hydraulic pistons was constructed and used in order to provide constant amount of restraint to a specimen even while it expands due to the welding heat [6]. The system was designed in such a way that it can be easily assembled in a pipe and easily disassembled after welding is completed.

Reduction of Forces Acting on Tack Welds in a Butt Joint

A research program was performed for the Department of Energy with an objective of minimizing forces acting on tack welds in a butt joint. The program was a part of a larger research program involving both M.I.T. and I.N.E.L. (Idaho National Engineering Laboratory) on automatic control of arc welding.

The uneven temperature distribution caused by the welding arc produces complex transient thermal stresses resulting in mismatch of parts to be joined unless they are securely held together. The joint mismatch that occurs during butt welding, which is shown in Figure 4-(a), can be explained by combining the information given in Figure 1. Suppose that a butt weld is being made with no tack weld, as shown in Figure 4-(a), each of the two parts being joined behaves as shown by Curve OABC in Figure 1. If deformations in regions near the welding arc when they start to cool are near Point A (or somewhere between Points 0 and B), the finishing end of the joint would open. This phenomenon normally occurs during gas metal arc and submerged arc welding of steel plates. On the other hand, when a joint is welded with shielded metal-arc process using covered electrodes, deformations of regions near the weld when they start to cool may be somewhere after passing Point B resulting in closing of the finishing end. This type of distortion is often called "rotational distortion" [1]

A common method of coping with the rotational distortion is to hold the joint with tack welds. This can be done relatively easily in manual welding of small parts. In case of automatic welding, however, dealing with the rotational distortion becomes a complex problem. When welding is performed by a robot, for example, tack welds must be made by a human welder thereby requiring additional

manpower and cost. On many occasions, tack welds are performed by an inexperienced person, resulting in less than perfect welds. Also, tack welds, even if they are perfectly made, act as major hazards during the subsequent root pass welding. In fact, it is difficult to completely melt the tack welds during root pass welding causing lack of penetration and other types of defects [7]. In submerged arc welding of a long butt joint of thick plates, forces acting on tack welds are so great that they often break during welding. In fact, Japanese shipbuilders experienced longitudinal cracking of the finishing end when they first introduced one-side submerged arc welding of large ship plates [8].

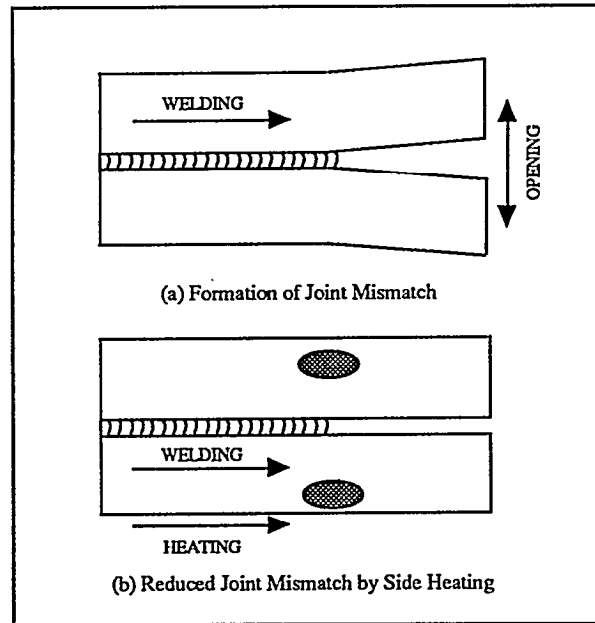


Figure 4 Mechanisms of Formation of Joint Mismatch by Side Heating

Chang, Park, and Miyachi performed experimental and analytical studies for reducing forces acting on tack welds during butt welding [9-11]. The basic idea used by Chang was to reduce the joint mismatch or the rotational distortion by side heating, as schematically shown in Figure 4-(b). By performing side heating while welding is performed, it may be possible to produce additional thermal stresses that can counteract those produced by welding. It is important, however, that the additional

heating not produce additional residual stresses.

Figure 5-(a) shows the experimental set up used by Chang [9]. Instead of using tack welds for holding plates to be joined, a semi-circular ring was attached to each end of the joint. The rings were instrumented with strain gages in order to measure changes of deformation at these ends. Although the rings were welded to the plates in experiments, these rings can be designed in such a way that they can be clamped to plates to be welded in actual fabrication. Efforts were made to reduce the opening of the finishing end by altering the thermal pattern in the weldment during welding. Two oxygen torches were mounted on a frame with a welding head so that the side heating system could be moved along with the welding arc. The position of the heating system relative to the welding head could be adjusted in three directions, x, y, and z, as shown in Figure 5(a), in order to control the side heating procedure. The system was used mainly for controlling the joint mismatch or the rotational distortion in a steel weldment.

Results on Steel Weldments. Figure 5 (b) shows typical results obtained on a low-carbon steel weldment, 36 inches (914 mm) long, 24 inches (610 mm) wide, and 0.5 inch (12.7 mm) thick, with no side heating. Data on the left figure show results for a weld without side heating, while data on the right figure show results for a weld with side heating.

Very soon after welding commenced, the starting end began to shrink. Note that when closing of a joint occurs, strains measured on gages attached on the outer surface of the ring would be tensile. The side heating caused little effect on forces acting on the ring attached to the starting end. On the other hand, forces acting on the finishing end were greatly affected by the side heating. On the specimen without side heating, the finishing end first opened a considerable amount as welding

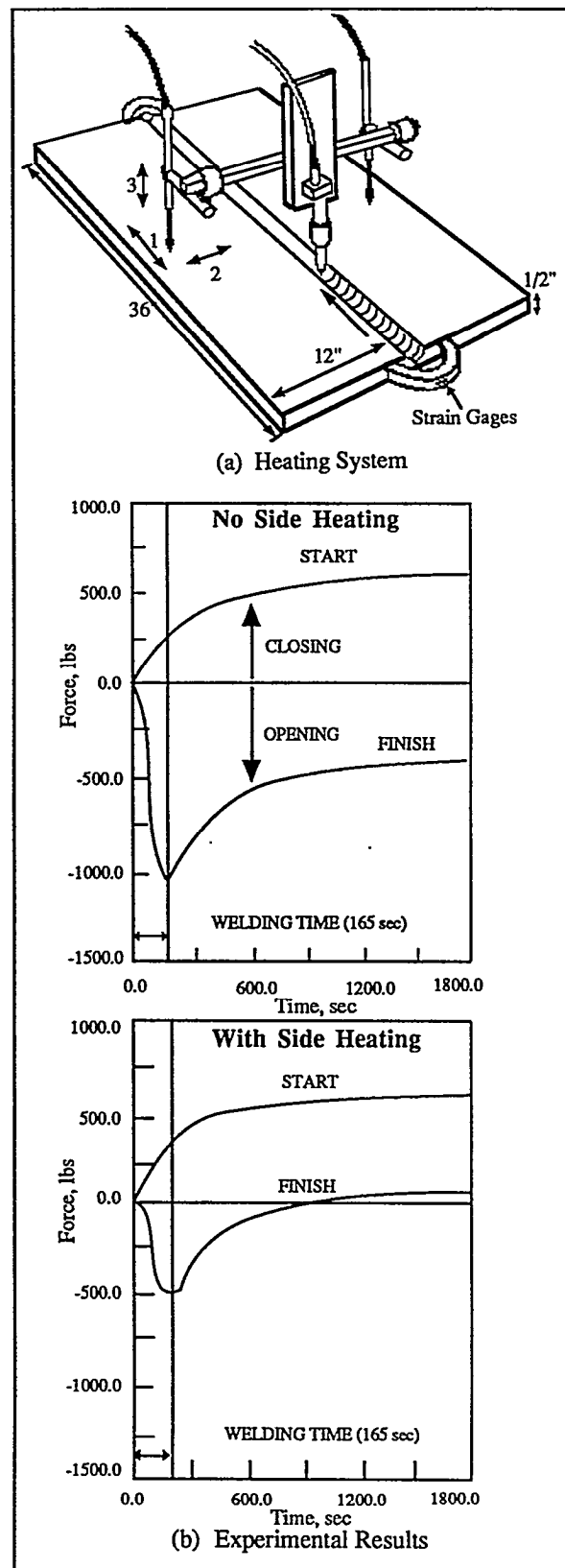


Figure 5 Reduction of Forces Acting on the Rings Attached to Starting and Finishing Ends of a Butt Weld

progressed, and it began to shrink after welding was completed. Almost all of the difference between the movement of the starting end and that of the finishing end was produced during welding. Welding was completed in 165 seconds, but it took approximately 1,800 seconds (30 minutes) before forces acting on the rings were fully developed.

The right graph of Figure 5-(b) shows results obtained on a steel weldment with side heating. It is clear that the amount of joint opening decreased significantly by use of the side heating. Results illustrate that the deformation at the starting end is little affected by the side heating. This indicates that the measurement at the starting end can be used as a control. In other words, the joint mismatch can be minimized as long as the strain measurements on the finishing end are similar to those obtained on the starting end.

An analytical study was made using a one-dimensional program to determine optimum conditions for side heating. It was found that the most effective method was to heat wide regions away from the weld to moderate temperatures (around 200°F or 93°C) to accomplish the following:

- (a) The side heating should produce thermal stresses large enough to counteract those produced by welding,
- (b) The side heating should not produce additional residual stresses.

In order to develop a strategy for the most effectively control the joint mismatch, a series of experiments as performed to study effects of torch movements in the x-, y-, and z-directions. It was found that forces acting on the ring (a simulated tack weld) at the finishing end can be significantly reduced by a proper side heating. For example, the maximum opening force observed on a ring attached to the finishing end was reduced from 1,125 pounds (506 kg) without side heating (welding

only) to only 105 pounds (47 kg) with side heating.

Results on Aluminum Welds. A limited amount of work was performed on aluminum welds by Park [10]. First, experiments were performed to study effects of side heating on forces acting on rings attached to both ends of aluminum butt welds 36" x 24" x 0.5" in size. Results were disappointing. For example, the maximum opening force observed on a ring attached to the finishing end increased from 300 pounds (135 kg) on a weld without side heating to 700 pounds (315 kg) on a weld with side heating. This is probably due to combined effects of the following:

- (a) Compared with steel, aluminum has a large heat conductivity (approximately 5 times that of steel). Therefore, the heat spreads much more rapidly in aluminum than in steel. In order to produce thermal stresses large enough to counteract those produced by welding using side heating there must be uneven temperatures caused by both the welding arc and the side heating. In an aluminum weld, the heat spreads so rapidly that temperature distributions caused by the welding and the side heating cannot be well separated.
- (b) Compared with steel, aluminum has a larger coefficient of linear thermal expansion (approximately 3.5 times of that of steel). Therefore, the best method for reducing distortion in an aluminum weld is to lower temperatures, not to increase them by additional heating.

It was decided to study effects of forced cooling on the joint mismatch during welding of an aluminum butt joint. Since it was difficult to have a heat sink that could travel with the welding arc, it was decided to cool the joint before welding and to keep the cooling system operating during the entire welding period. Crushed dry ice particles were used to cool

regions near the weld. Then the maximum force observed on a ring attached to the finishing end decreased from 300 pounds (135kg) without cooling to mere 30 pounds (13.5 kg) with cooling. The results show that the key for reducing the joint mismatch (and perhaps residual stresses also) in an aluminum weld is to keep the temperatures in the weldment as low as possible.

Reduction of Residual Stresses and Distortion in Weldments in High-Strength Steels

Various types of high-strength steels are increasingly used for welded marine structures to reducing structural weight and improve service performances. For example, the U. S. Navy, having used HY-80 and HY-100 steels for many years for submarine hulls is considering using HY-130 steel for pressure hulls of future submarines. HY-80, HY-100, and HY-130 steels are quenched-and-tempered steels with the minimum specified yield strengths of 80,100, and 130 ksi (552,689, and 896 MPa), respectively. Since yield stresses of these steels are high, there is always a possibility of producing very high residual stresses in some regions near welds, including at the end of repair welds and in regions near structural discontinuities (such as the end of a fillet weld connecting a flat plate and a stiffener). High transient thermal stresses during welding and residual stresses may cause some of the following problems:

- (a) Since steels with higher strengths tend to become more sensitive to weld cracking, higher transient thermal stresses can promote weld cracking.
- (b) Since steels with higher strengths tend to become more sensitive to environmental effects such as stress corrosion cracking and hydrogen embrittlement, high tensile residual stresses may promote environment assisted cracks during service.
- (c) Since design stresses are higher for

structures of higher strength steels, these structures tend to have increased tendencies of fatigue failures. Higher tensile residual stresses may promote these fatigue fractures.

Efforts have been made to study methods of reducing residual stresses and distortion in high-strength steel weldments. A one-year research program was conducted in which Bass and Vitooraporn performed experimental and analytical studies on residual stresses and distortion in bead-on-edge welds in three types of steels including low-carbon steel (ABS Grade B), HY-100, and HY-130 steels [12,13]. HY-100 and HY-130 steels were made available through the U.S. Navy.

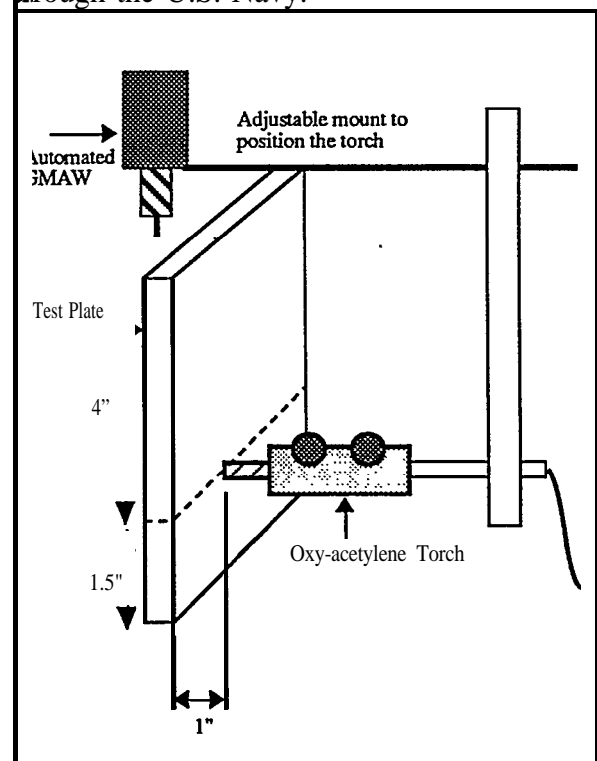


Figure 6 Experimental Set-up Used by Bass and Vitooraporn

Figure 6 shows the experimental set-up. Test specimens were 5.5 inches (140 mm) wide, 18 inches (457 mm) long, and 0.5 inch (12.7 mm) thick. Welding bead was laid using gas metal arc process along the upper longitudi-

dinal edge of a specimen placed in the vertical position. An E70S filler wire 0.045 inch (1.1 mm) in diameter was used for all experiments.

Typical welding conditions were as follows:

Polarity: direct current reverse polarity
 Shielding gas: 98% argon, and 2% oxygen
 Welding current: 230 Amperes
 Arc voltage: 25 Volts
 Arc travel speed: 0.300 in/set (7.6 mm/sec).

Some specimens were welded without side heating, while others were welded with side heating using an oxyacetylene torch positioned 4 inches (102 mm) from the upper edge of the specimen. The side heating conditions were selected in order to produce the maximum temperatures of approximately 200°F (93°C) in the specimen.

During welding, measurements were made of: (1) strains using electric resistance strain gages, (2) temperatures using thermocouples, and (3) deformation using dial gages. After welding was completed, residual stresses were determined by a stress relaxation technique in which a narrow strip containing strain gages was removed from the specimen. Experimental results were analyzed using (a) analytical modeling techniques and (b) numerical techniques using a finite element method.

Experimental results are summarized in Figures 7 through 9. Figure 7 shows results obtained on specimens in low-carbon steel. Figure 7-(a) shows distortions measured by a dial indicator placed at the center of the plate during welding and after welding of specimens. Figure 7-(b) shows relationships between the lateral distance from the weld and longitudinal residual stresses. Figures 8 and 9 show similar data obtained on specimens in HY-100 steel and HY-130 steel, respectively.

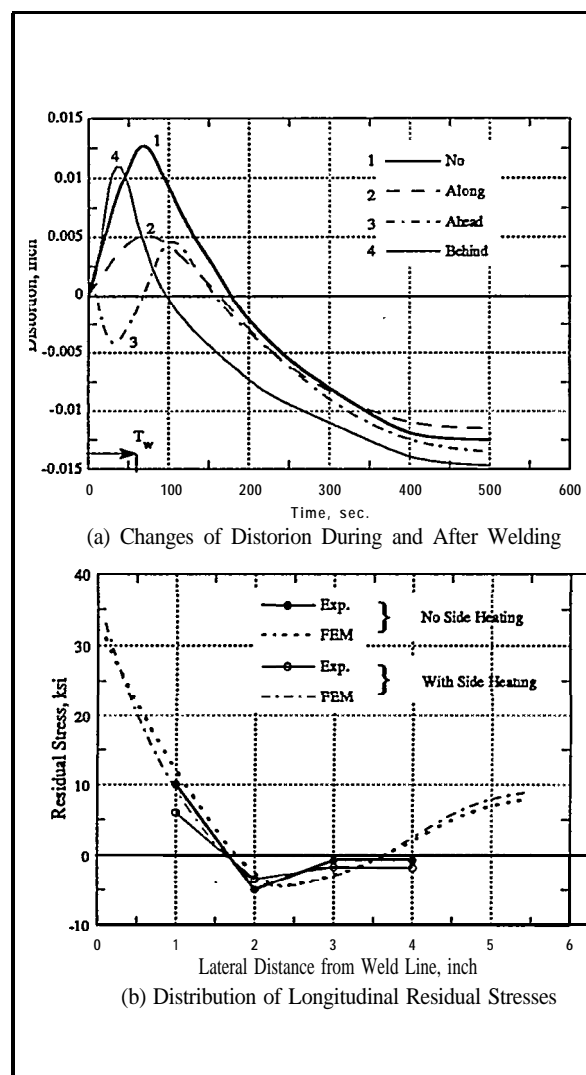


Figure 7 Reduction of Distortion and Residual Stresses by Side Heating in Low-Carbon Steel Specimens

The results may be summarized as follows:

(a) Distortion Changes. Figures 7-(a), 8-(a), and 9-(a) show changes of deformation during and after welding measured at the mid-length of the specimen (9 inches or 229 mm from the edge) of specimens in low-carbon steel, HY-100 steel, and HY-130 steel, respectively. Each of the figures contain data obtained under the following four conditions:

Condition 1: No side heating;

Condition 2: The side heating torch positioned along the

welding head;

Condition 3: The side heating torch 9 inches (229 mm) ahead of the welding head; and

Condition 4: The side heating torch 9 inches behind the welding head.

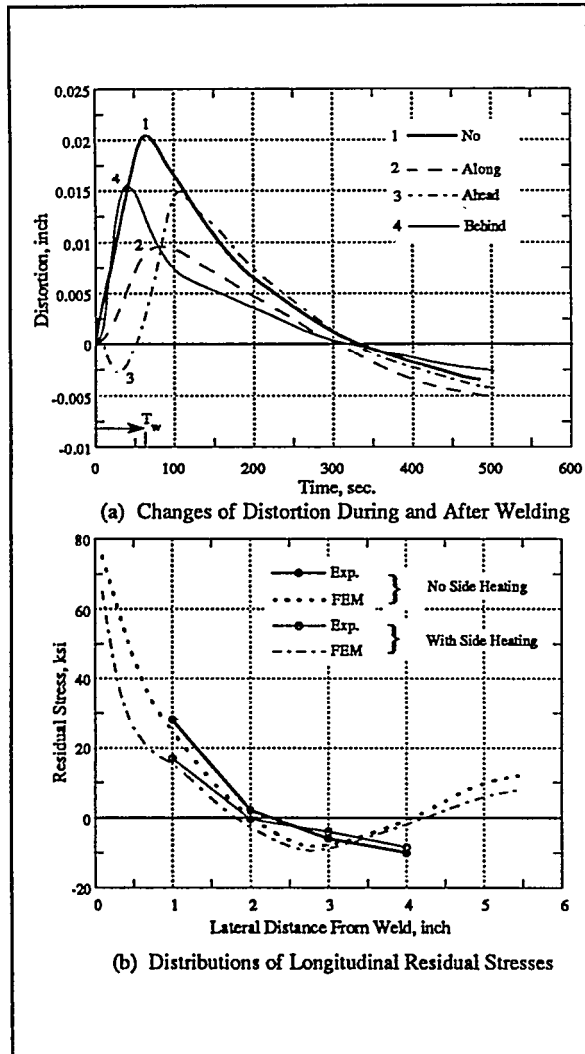


Figure 8 Reduction of Distortion and Residual Stresses by Side Heating in HY-100 Steel Specimens

The side heating behind the welding arc (Condition 4) was found to be not as effective in reducing distortion. In other words, it was too late to try to reduce distortion after welding. The side heating ahead of the arc (Condition 3)

caused rather complex changes of distortion. The plate first moved by the heating torch, and then it moved again by the welding torch. Researchers have come to a conclusion that the side heating ahead of the arc is not a recommended method since it produces distortion changes that are too complex. Researchers favor the effects created by the side heating along the arc (Condition 2), since changes of distortion during the entire period of welding and subsequent cooling were kept rather small. It has been concluded that the side heating along the welding arc is a good method for controlling distortion.

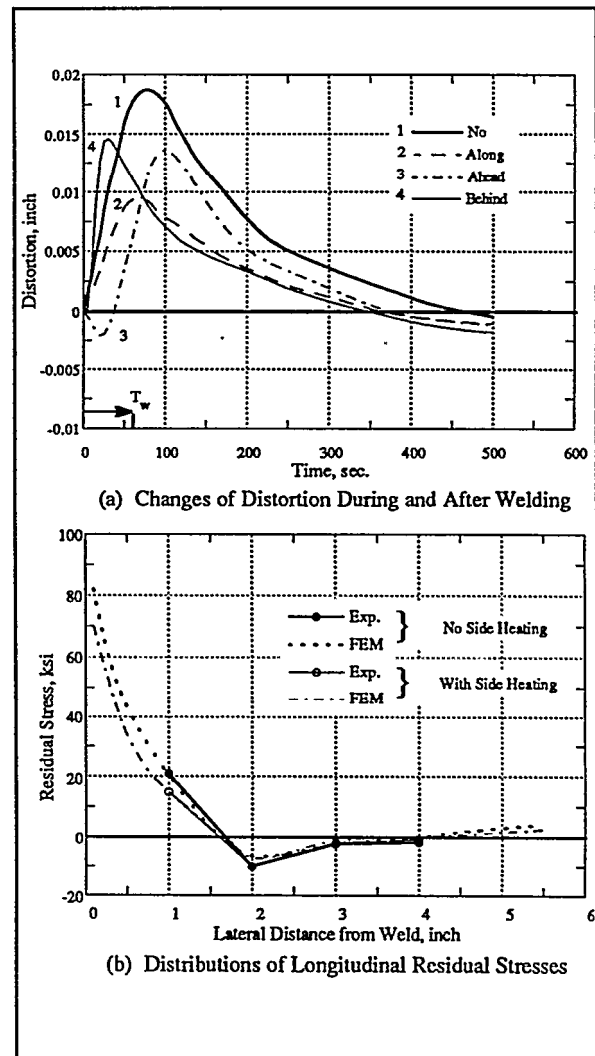


Figure 9 Reduction of Distortion and Residual Stresses by Side Heating in HY-130 Steel Specimens

(b) Residual Stresses. Figures 7-(b), 8-(b), and 9-(b) show lateral distributions of longitudinal residual stresses, σ_x , along the middle section of the specimen in low-carbon steel, HY-100 steel, and HY-130 steel, respectively. Shown in each figure are four sets of curves as follows:

- (a) Results on a specimen without side heating:
 - (a-1) Experimental data; and
 - (a-2) Calculated results using the finite element method
- (b) Results on a specimen with side heating:
 - (b-1) Experimental data; and
 - (b-2) Calculated results using the finite element method.

The results show that residual stresses were reduced to some extent by the side heating.

Conclusions on the Effectiveness of the Side Heating Technique. On the basis of the results obtained in this study and the previous study on forces acting on tack welds, the following comments as to the effectiveness of side heating as a method of reducing residual stresses and distortion can be made:

- (1) Forces Acting on Tack Welds. The side heating technique is very effective in reducing joint mismatch and forces acting on tack welds in a steel weldment.
- (2) Distortion. Distortion can be reduced significantly by side heating, especially by side heating along the welding arc.
- (3) Residual Stresses. The side heating can accomplish reduction of residual stresses to a certain extent; however, the extent of reduction of residual stresses is less than that of reduction of distortion. This is understandable, because the side heating can significantly affect the movement of a weldment as a whole. But the effectiveness of side heating for reducing residual stresses in regions near the weld are less, because residual stresses are more affected by

temperature distributions close to the weld. More drastic reduction of residual stresses may be achieved by locally heating the regions near the weld to moderate temperatures after welding is completed. In fact, Greene and Holzbaur found in the 1940's that residual stresses could be reduced significantly by a technique called "low temperature stress relieving" [14, 15]. This system employs the oxyacetylene flame to heat simultaneously two strips, one on each side of a weld joint, to 500°F (260°C), in such a way their expansion stretches the weld plastically, reduces the peak residual stresses, and alters the stress gradient [15]. On the basis of the new study, a significant reduction of peak residual stresses in a weldment in a high-strength steel may be accomplished by heating a wide region to only moderate temperatures around 200°F (93°C). Further research is needed for evaluating the usefulness of the low-temperature stress relieving on high-strength steel weldments for critical structures.

- (4) Aluminum Welds. The side heating technique is not recommended on an aluminum structure. In fact, the basic principle for minimizing residual stresses and distortion in an aluminum weld is to minimize the heating of the weldment.

OTHER RESEARCH ACTIVITIES

Presented below are brief summaries of several other projects related to residual stresses and distortion in weldments.

Forming of Steel Plates by Line Heating with a High-Power Laser Beam

A technique involving heating with an oxyacetylene torch has been widely used for

straightening distorted plates as well as forming plates into various shapes. For example, Japanese shipbuilding companies extensively used line heating techniques for bending steel plates [1]. A research project was performed to investigate whether steel plates can be formed by use of the line heating technique with a high-power laser beam (approximately 5-10 kilowatts in power) instead of an oxyacetylene torch. The program was performed for the U.S. Navy through Todd Pacific Shipyards Corporation [16-18]. Tests were performed on low-carbon steel plates 1/4 through 1 inch (6.4 through 25.4 mm) thick. Some tests also were made on plates in HY-80 steel and other low-alloy high-strength steels.

Results obtained in the program may be summarized as follows.

- (1) The laser line heating is a very effective method of forming steel plates, especially with a thickness of around 1/4 to 1/2 inch (6.4 to 12.7 mm). The practical maximum thickness for laser line heating appears to be around 1 inch (25.4 mm), and the practical maximum heat input is approximately 65 KJ/in (165 KJ/cm).
- (2) Material degradations were observed on specimens subjected to laser heating using high heat input (54 KJ/in or 137 KJ/cm). However, the material degradation could be eliminated, practically speaking, by applying multipass heating techniques using a small heat input (3 passes of 18KJ/in per pass).

It should be noted that all of the novel techniques for measuring out-of-plane distortion described earlier in this paper were successfully used in this research program.

Intelligent System for Flame Straightening of Panel Structures

Distortions which occur during the assembly of

steel panel plates can be removed by flame straightening - a technique that has been used for a number of years in the shipbuilding industry. Many years of experience are usually needed to acquire the skill required to correctly perform flame straightening of complex structures such as ships. The problem that the industry faces now is that many of the skilled human experts have retired or are retiring, and it is extremely difficult to secure younger people who are willing to spend many years to acquire these needed skill. One way to improve the situation is to develop a robot capable of not necessarily replacing a human worker but helping a human worker. A study was performed with the ultimate objective of developing an intelligent machine capable of performing flame straightening on a deck of a ship super structure [19]. This study thus far includes (a) development of algorithms for determining heating conditions and (b) development of sensors needed for in-process sensing and control of robot movements.

Development of a Knowledge-Based System for Minimizing Out-of-Plane Distortion of Welded Panel Structures

Weld distortions in a complex structures are affected by many parameters. Some of the parameters include:

- (a) Structural geometry
 - Plate thickness
 - Frame spacing
- (b) Welding processes
 - Shielded metal arc
 - Gas metal arc
 - Submerged arc
- (c) Material type
 - Low-carbon steel
 - High-strength steel
 - Aluminum alloys
- (d) Joint type:
 - Butt joint
 - Fillet joint
- (e) Distortion type

Distortion due to angular change
Buckling distortion
Longitudinal shrinkage
Transverse shrinkage
Longitudinal bending distortion.

For minimizing distortion of welded structures, it is very important to select proper combinations of these parameters. Regis has performed a preliminary study for developing a computer-aided system for selecting proper combinations of these parameters [20]. His work covers mainly out-of-plane distortion of panel structures composed of a flat plate with longitudinal and transverse stiffeners fillet welded to the plate.

CONCLUSION

A weldment undergoes complex changes in thermal stresses during welding, and in residual stresses and distortion after welding is completed. It is important to understand the mechanisms of formation of these stresses and strains in order to develop rational methods for controlling and reducing these stresses and distortion. The most effective method for achieving the objective of controlling and reducing these stresses and distortion is to apply proper controls during welding, while non-elastic strains that cause these stresses and strains are being formed. The concept of providing additional real-time control is not realistic in fabrication using manual welding, but it should be possible in fabrication using automatic welding.

The first part of this paper covers summaries of experimental and analytical studies for controlling and reducing residual stresses and distortion in several types of fundamental welded joints. The author hopes that some of the basic principles developed in these studies are applicable to actual constructions of welded marine structures. The second part provides a brief summary of other activities related to

residual stresses and distortion. The author also hopes that a collection of these efforts will provide engineers and managers in the ship-building industry scientific basis for design and fabrication of more reliable welded marine structures with reduced costs.

ACKNOWLEDGMENTS

The author wishes to acknowledge the hard work by all the personnel who participated in the studies cited in this paper. The author also acknowledge all the organizations that provided financial support for the studies including the Division of Engineering and Geosciences of the Office of Basic Energy Sciences, the Department of Energy and the National Sea Grant College Program of the National Oceanic and Atmospheric Administration. Matching funds for the Sea-Grant supported research program were provided by a group of companies including Hitachi, Ltd., Hitachi Shipbuilding Co., Ishikawajima Harima Heavy Industries, Kawasaki Heavy Industries, Mitsubishi Heavy Industries, Mitsui Engineering and Shipbuilding Co., NKK, Sumitomo Heavy Machinery Co., Takenaka Komuten (Construction Co.), and Toshiba Corp.,

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Shipyard Aluminum/Steel Welded Transition Joints IVB-4

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ABSTRACT

Aluminum to steel explosion welded transition joints are used in shipbuilding to attach aluminum superstructures to steel hulls. This paper summarizes long term studies to determine causes of separations and describes actions to prevent separations.

The aluminum/steel transition joints are manufactured by the explosion welding process and tested in accordance with MIL-J-24445. Traditional transition joints consist of alloyed aluminum bonded (by the explosion weld) to mild steel with an interlayer of low alloy aluminum. In 1989, production began using an improved transition joint product with the addition of a titanium interlayer between the steel and the low alloy aluminum. Laboratory testing showed the improved product had greater strength and temperature resistance. However, when this product was put into production, disbonding occurred at an alarming rate. As a result, it was discovered that bond notch toughness is a critical property even though it was not required to be measured by MIL-J-24445. To improve the notch toughness while preserving earlier beneficial improvements, a ductile copper nickel (CUNI) interlayer was added between the steel and the titanium.

This paper describes the study results and the development of the latest generation of aluminum steel structural transition.

DEFINITIONS

ABS- American Bureau of Shipping; refers to their steel plate classifications

AL- Aluminum metal

ASTM- American Society for Testing Materials

CUNI- Copper Nickel alloy metal

DT- Dynamic Tear, ASTM standard E-604; measurement of energy absorption to break a notched specimen considerably

larger than an IZOD specimen

EXW- Explosion Weld; the process of fusing two metals together at a bond surface by using the force of an explosion

IZOD- ASTM standard E-23-82; measurement of energy absorption to break a specimen similar to Charpy vee notch except that the pendulum strikes a cantilevered specimen

MIL- Military Specification (U.S. Government)

SCAST- Structurally Critical Aluminum Steel Transition

TI- Titanium metal

UT- Ultrasonic Testing

BACKGROUND

Aluminum cannot be arc welded directly to steel because of metallurgical incompatibility. Aluminum to steel welds can be produced using cold welding processes, such as explosion welding (EXW). Conventional arc welding processes then can be used to attach the EXW transition to respective compatible metal components. This combination provides a crevice free, fully welded joint between aluminum and steel. This is a significant advantage over mechanical fastening by riveting or bolting.

The aluminum to steel transition joints typically are welded to a steel coaming about five inches above the top-most steel deck. The EXW transition joint supports the bulkhead plating, vertical stiffeners and framing. See figure 1 for a typical design. Early installations used 35 mm (1-3/8 in) thick transition joints. Recent designs use 19 mm (3/4 in) thick transition joints.

In the mid-1980's, some shipboard bonded joints separated as a result of normal operations in high sea state conditions. These disbonds resulted in closely focused attention on all bond joints. The separations were puzzling because these EXW transition joints were

designed to be the "strong link" in the structural chain (stronger than the aluminum plating welded to the joint).

Ships under construction were closely examined. For about a year, locations of disbond repairs were monitored to analyze why the disbonds were occurring. Most disbonds were associated with butt welds in the transition strips. Butt welding causes local disbonds, typically less than 10 mm (3/8") due to weld heat and stress. Also, 92% of the disbonds were in narrow strips which have less thermal mass to absorb the welding heat input, resulting in higher temperatures-at the bond during fillet welding. All known disbonded locations have always been repaired before any ship left the shipyard. Disbonding in service is rarely reported, so apparently disbond in fleet service is unusual.

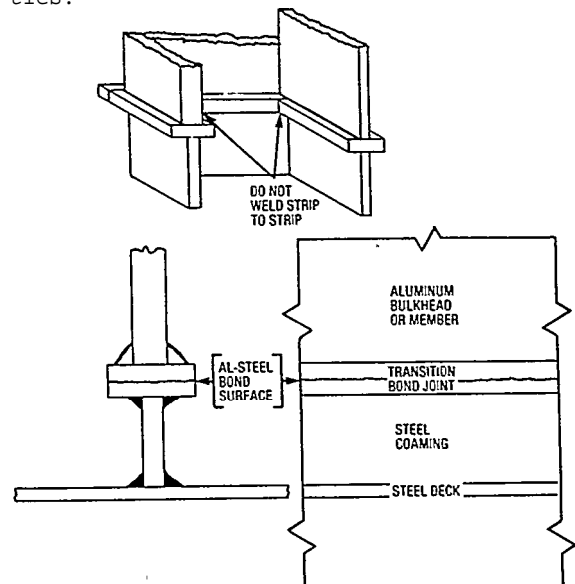
In 1990, 38 mm (1.5 in) thick improved trimetallic (AL-TI-STEEL) with higher strength ABS grade DH 36 steel base layer transition was placed into production after extensive laboratory research. The research confirmed high tensile strength and temperature resistance. In production, four of eight weldments developed disbonds of up to 70% of their length. Some disbonding occurred several hours or days after welding was completed. The disbonded areas continued to grow for several days after inception, eventually growing to several feet long. That 38 mm thick, DH 36 based trimetallic was immediately pulled from production and ordinary bimetallic was substituted. No 38 mm trimetallic was ever actually installed on board any ship. The disbonding was attributed to a combination of low notch toughness, large weld related stresses (due to full penetration welding and high yield strength steel), and restraint provided by the large weldments. A 19 mm (3/4") thick improved trimetallic with an ordinary strength steel base layer transition remains in production with no known disbond to date.

Transition Joint Manufacture

Aluminum to steel bonded transition joints are manufactured in accordance with the requirements of MIL-J-24445. The only process currently used for manufacture of shipboard transition joints in the USA is explosion welding. A roll bonded product is being evaluated, but results were not available in time to be included in this paper. Reference (1) provides a thorough description of the technology and of the development of aluminum to steel transition joints for shipboard applications. References (2) and (3) provide a summary of the process. Figure 2 depicts the basic explosion bonding process.

In the early explosion bonding devel-

opment work discussed in Reference (1), it was observed that a direct explosion weld between aluminum 5000 series alloys and steel exhibited low strength and poor toughness. The deficiency was corrected by insertion of an interlayer of unalloyed aluminum, type 1100, between the marine grade 5456 aluminum and the steel. The original 35 mm (1-3/8 in) thick transition joints consist of 6.3 mm (1/4 in) thick 5456 aluminum alloy bonded to an interlayer of 9.5 mm (.375 in) thick 1100 aluminum and a base of 19 mm (0.75 in) steel. Later, 19 mm (3/4 in) thick transition joints were made using 3.2 mm (0.125 in) thick 5456 or 5086-aluminum alloy bonded to a 6.4 mm (0.25 in) thick interlayer of 1100 aluminum and a base of 9.5 mm (0.375 in) steel. Although these products are actually comprised of three alloy layers, they are commonly referred to as "bimetallic" transition joints. Besides 1100 aluminum, other interlayers may be employed to obtain various bond properties.



Z-10322

Figure 1. Typical Joint Design

Transition Joint Quality Testing

Aluminum to steel welded transition joints are quality tested in accordance with the requirements of MIL-J-24445. This specification requires 100% ultrasonic testing (UT) of every plate by straight beam transducer to detect areas of non-bond. Although ultrasonic testing will reliably detect non-bond, it can not detect areas of low bond strength.

In addition to UT, one plate from every lot, or 1 in 10, whichever is more frequent is mechanically tested. Test specimens must be cut from two diagonally opposite corners of the selected plates. Ram tensile tests and a side bend test are required. Neither test will evaluate notch toughness. Since EXW transition joints rarely pass side bend

test, MIL-J-24445 provides bond shear strength and chisel testing as a substitute for side bend. The chisel test is a qualitative but unreliable indicator of notch toughness. Before tensile testing, some samples are heat treated 15 minutes at 315 C (600 F) to simulate the "as welded" condition. Specification requirements are: 55.2 MPa (8,000 PSI) minimum shear strength; 75.8 (11,000 PSI) minimum tensile strength; and no bond failure in either the side bend test (if used) or the chisel test (if substituted).

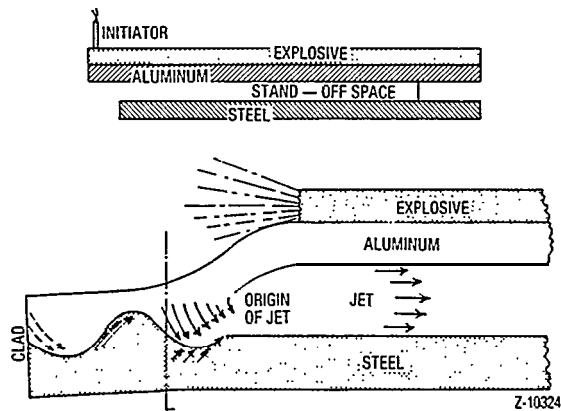


Figure 2. Parallel arrangement for explosion cladding and subsequent collision between the prime and backer metals that leads to jetting and formation of wavy bond zone.

Bond Separations Study

Reference (3) discusses in detail the bulk of the research. The following paragraphs provide a summary of reference (3).

(1) BOND TEMPERATURE- Thermocouples were located at the bond surface under fillets to measure the actual bond temperatures occurring during various weld processes. These tests showed that shipyard welding practices were not overheating the bond joints above the 315 C (600 F) allowable temperature.

(2) FILLET SIZE- Oversize aluminum fillets out to the edge of the strip did not cause degradation in bond strength.

(3) BOND MATERIAL CHANGES OVER TIME- Bimetallic bond tensile strength has not appreciably changed with time, although there are variations between manufacturers. Independent testing and vendor review showed that all manufacturers were testing in compliance with MIL-J-24445.

(4) DESIGN WIDTH- The standard recommendation is to provide transition strip widths four times the thickness of the aluminum member (see figure 1). Statistical analysis in reference (3) showed this standard is marginally ac-

ceptable. Wider transition joint strips could be used to lower stress, but with undesirable weight increase.

(5) RESTRAINT & WELD SHRINKAGE STRESS- Restraint and thermally induced stresses are significant, but don't normally, in and of themselves, cause disbonding. However, when the DH 36 based trimetallic went into production, restraint provided by a 25.4 mm (1 in) thick HY-80 steel web combined with thermal stresses due to full penetration welds was sufficient to initiate disbonding.

The studies to date clearly show that structural transition reliability can best be improved by improving the provisions of Mil-J-24445. The 38 mm (1.5 in) DH 36 trimetallic bond was tested well beyond existing provisions, yet was found unsuitable for structurally critical ship production applications. The DH 36 trimetallic's strength was nearly double the minimum and it was much more temperature resistant. It even passed the side bend test (usually). Every plate was tested, although MIL-J-24445 only requires samples from one plate in ten. However, MIL-J-24445 does not require notch toughness testing and the DH 36 trimetallic had slightly lower notch toughness than the standard bimetallic product. MIL-J-24445 is now undergoing revision and many changes are a direct result of the recommendations reference (3) and the lessons learned from the DH 36 trimetallic.

SCAST

SCAST is an acronym for Structurally Critical Aluminum Steel Transition. The Navy expressed a need for a highly reliable, high strength aluminum steel transition joint with a higher strength steel substrate for a structurally critical location. The product was intended to join the CG 47 class sheer strake to the forward side of the superstructure. While the DH 36 trimetallic product discussed earlier met the target of improving tensile strength and thermal degradation resistance, initial production clearly showed that notch toughness was important.

Improved notch toughness became an additional goal for development. The initial fabrications showed that weld shrinkage stresses were sufficient to initiate a disbond, probably at a locally weak area. Once the disbond began, it easily progressed through the brittle TI/steel bond until the shrinkage stresses were relieved. Thus the DH 36 trimetallic was not suitable as a Structurally Critical Aluminum Steel Transition.

The principal manufacturer of the trimetallic product produced an experimental quadmetallic product to solve the notch toughness problem. The goal was to develop an aluminum steel transition joint with at least twice the strength, improved heat resistance, and twice the

notch toughness of the bimetallic product. The principal difference between their SCAST and the trimetallic is the addition of a copper nickel (CUNI) layer between the higher strength steel and the titanium. The exact formulation and the special EXW processing are regarded as proprietary by the manufacturer.

As MIL-J-24445 did not address a need for bond notch toughness, three tests were used to quantify the relative notch toughness of different material compositions. The goal was to develop a SCAST product that would have at least twice the notch toughness of conventional bimetallic products, regardless of which test method was used. The final SCAST formulation meets this goal. The simplest test consisted of cutting a notch into both ends of the welded tensile samples. The notch geometry was the same as that for a dynamic tear specimen, ASTM E-604. Also, notched specimens were prepared in accordance with ASTM E-23-82 with notches placed at bimetallic AL/steel bond and quadmetallic steel/CUNI, CUNI/TI and TI/AL bond surfaces. Finally, dynamic tear (DT) specimens were prepared with notches at the CUNI/TI bond, which was found to be the lower energy bond by earlier IZOD tests.

The notched tensile test showed that the strength advantage of the trimetallic and initial quadmetallic products relative to the standard bimetallic product did not remain after notching. In the notched tensile test, bimetallic bond strength dropped from about 82.7 MPa (12 KSI) for unnotched specimens to about 41.4 MPa (6 KSI) for specimens notched at the bond. Quadmetallic tensile bond strength dropped from about 172 MPa (25 KSI) to about 41.4 MPa (6 KSI) for the early product. After these tests, the quadmetallic material formulation was slightly changed to further improve notch toughness, resulting in SCAST-2 which had a notched tensile strength of 103 MPa (15 KSI). After more testing, the EXN manufacturing process was again modified to further improve notch toughness, re-

sulting in SCAST-3. As the desired notched tensile stress for SCAST should be at least twice that of bimetallic, it appears that the third generation quadmetallic meets this goal.

The IZOD testing showed that the energy absorption of quadmetallics was vastly better than bimetallic. Bimetallic samples absorbed, on the average, about 12.2 Nm (9 foot-pounds). Improved quadmetallic SCAST samples, on the average, absorbed about 59.6 Nm (44 foot-pounds). The later test results may not be valid because SCAST IZOD specimens would not fail at the bond. Even with the notch at the bond, there was no disbonding at all. Instead, the specimens plastically bent in the 1100 aluminum. Thus, what was really measured was the energy absorbed in plastic deformation of the aluminum, not the energy absorbed in disbonding. Numerically, the quadmetallic SCAST surpassed the goal of absorbing twice the energy of bimetallic bonds.

The dynamic tear (DT) testing also showed that the energy absorption of the improved quadmetallic SCAST was significantly better than bimetallic. Bimetallic DT samples absorbed, on the average, about 65.1 Nm (48 foot-pounds). Improved quadmetallic DT samples, on the average, absorbed about 228 Nm (168 foot-pounds). The improved quadmetallic SCAST-3 surpassed the goal of twice as much energy absorption as bimetallic. As disbonding occurred in both types of product specimens, this test is believed to be a more representative measure of notch toughness of the bonds. Mil-J-24445 is currently being revised to incorporate dynamic tear testing. There will be further product testing before numerical values can be incorporated into the revision.

Cost Considerations

Improved SCAST transition joint material costs about 10% more than conventional bimetallic material in plate form. The increased material cost for the SCAST material prompted a study of ways to reduce the cost. This cost in-

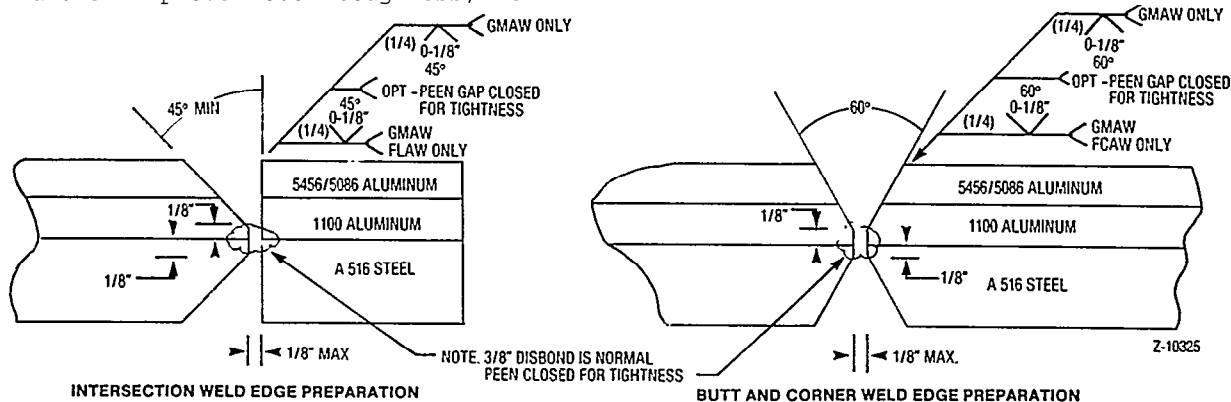


Figure 3. Recommended butt joints in transition strips

crease is offset by improved safety margin (reliability) and by using narrower strips due to the higher tensile strength of the trimetallic. The improved resistance to thermal degradation of SCAST and trimetallic materials permits high speed, low cost plasma cutting versus the high cost mechanical cutting used for heat sensitive conventional bimetallic strips. That improved thermal degradation resistance also permits production savings when high deposition rate spray GMAW and FCAW processes are used to install the strips (versus lower heat pulsed GMAW). Overall, the SCAST product can actually cost less than the standard bimetallic.

CONCLUSIONS

An (ABS DH 36) steel-titanium-aluminum explosion welded transition joint was found to be highly susceptible to disbonding in a production environment. Laboratory testing showed the bond was more resistant to thermal degradation and had much higher strength than bimetallic joints. Examination of disbonded weldments showed disbond initiation and growth in the titanium to steel bond surface. A similar but thinner trimetallic with ordinary strength steel has not experienced any disbonds. It was concluded that, because strength and surface hardness are related, the DH 36 trimetallic may have a more brittle bond. Research then began to develop a product preserving the advantages of the DH 36 trimetallic (high bond strength, improved temperature resistance) but with improved notch toughness. The research successfully produced Structurally Critical Aluminum Steel Transition (SCAST) joints. Compared to conventional bimetallic bond joints, SCAST improves the bond strength from 82.7 MPa (12 KSI) to 172 MPa (25 KSI), improves temperature resistance from 315 C (600 F) to 515 C (950 F) and improves dynamic tear notch toughness from 65.1 Nm (48 Ft-Lbs) to 228 Nm (168 Ft-Lbs).

In conclusion, SCAST transition joints greatly improve the reliability while offering potentially lower overall costs.

RECOMMENDATIONS

MIL-J-24445

Naval Sea Systems Command (NAVSEA) is currently in the process of revising MIL-J-24445 to add a new grade of material (SCAST) which would require notch toughness testing, higher bond strength, and higher heat soak before testing. Other changes planned will require chisel testing for all grade products and a revised sampling plan with testing near the EXW initiation point and the farthest corner.

Design

A conscientious designer will want to use the best materials within cost constraints. The conventional bimetallic joint developed in the 1960's demonstrates lower strength, is much more sensitive to heat, and now is much more "brittle" (low notch toughness) than the newest SCAST products. Clearly, SCAST is a better material by every engineering measurement. If the designer is free to choose minimum widths, and if high speed plasma cutting processes is an acceptable alternative, SCAST designs will actually be a lower cost alternative to bimetallic. Even if the width cannot be reduced and plasma cut edges are not acceptable, the increased reliability may justify the slight increase in purchase cost for saw cut strips.

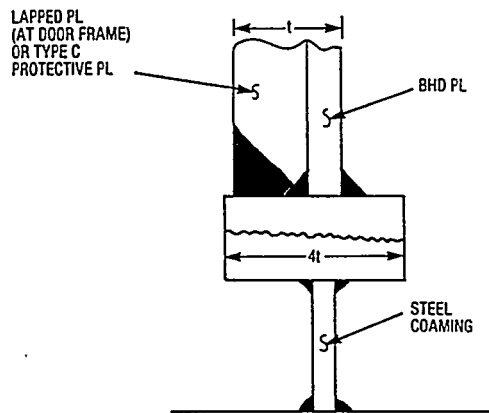
There are some design suggestions from reference (3) which should be repeated here. The standard rule of thumb is to use strip widths of 4 times aluminum plate thickness. However, statistical knowledge of actual strengths of welded transition joint and structural plating should be considered in establishing design guidelines. If a 1% disbond rate is considered acceptable, the recommendation based on data reported in reference (3) would be to provide bimetallic strip widths of 4.24 times the thickness of the aluminum plating. Minimum widths of the SCAST material would be on the order of 3 to 1. These recommendations may be modified to take into account the width of weld fillets and needed reliability at strip butts where notches may exist.

The designer should always specify a partial penetration butt design (as shown in figure 3) and should give preference to designs which minimize the number and proximity of butt welds. See figure 4 for some ideas.

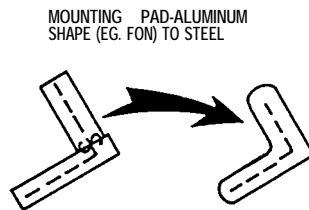
Production

The peak bond joint temperature of bimetallic transition joints is limited to 315 C (600 F) by the manufacturers. This limits the processes which can be used for welding. It also requires cool down time between weld passes to reduce interpass. SCAST is not nearly as temperature sensitive. Tensile tests show no significant degradation at significantly higher temperatures. Future research will determine the acceptable peak and interpass temperatures based on tensile and dynamic tear testing after exposure to various high temperatures.

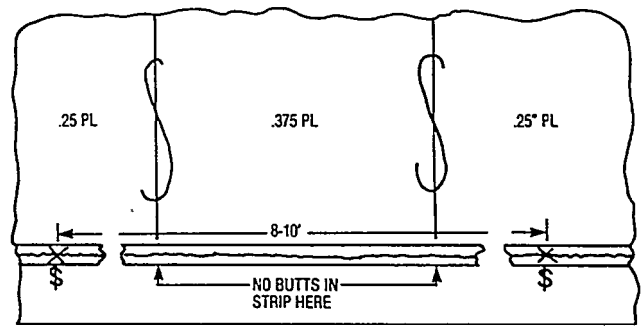
When plasma cutting, the highest feasible travel speed should be used and the composite plate should be submerged. Periodic tensile and bend testing of plasma cut strips would be a wise precaution. Such samples should be cut near the explosion weld initiation point, if that is known.



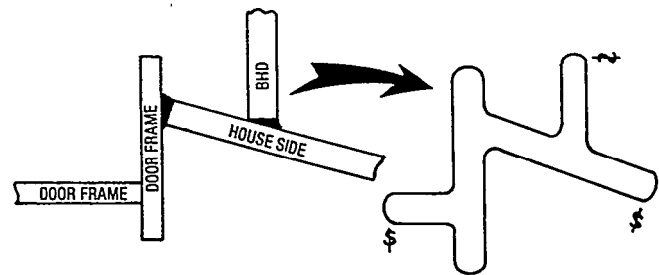
1. WHERE PLATE HAS LAPPED PLATE, DESIGN STRIP WIDTH SHOULD CONSIDER TOTAL THICKNESS



3. SIMPLIFY BY PLASMA CUTTING PADS FROM PLATE



2. MINIMIZE BUTTS IN STRIPS. USE FULL LENGTH STRIPS (8-10" TYP) WITH WIDTHS SIZED TO THICKER PLATING



4. SIMPLIFY BY CUTTING COMPLEX INTERSECTIONS WITH PLASMA

Z-10328

Figure 7. Some designer recommendations

SUMMARY

Some aluminum to steel bimetallic transition joints were disbonding in ships under construction and, to a lesser extent, in the fleet. This was unusual because the strips were designed to be stronger than the aluminum plating attached. Studies were made to determine the causes and recommend corrective measures. Several possible causes were found, some eliminated, and preventative measures instituted. The most significant improvements were in design and materials. During the course of the study, a new trimetallic (aluminum-titanium-steel) transition joint was certified to MIL-J-24445 and introduced into production. The trimetallic design provides higher strength and higher resistance to heat degradation during installation welding while offering potentially lower overall costs. However, the notch sensitivity of the trimetallic titanium to steel bond lead to further material improvements through the development of a quadmetallic (aluminum-titanium-copper nickel-steel) Structurally Critical Aluminum Steel Transition (SCAST). Compared to

conventional bimetallic aluminum steel transition, SCAST has twice the tensile strength, twice the notched tensile strength, four times the dynamic tear notch toughness, and extends heat degradation resistance from 315 C (600 F) to nearly 538 C (1000 F). MIL-J-24445 is being revised to incorporate lessons learned during the study reported in this paper.

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2. "Dupont Detacouple Structural Transition Joints for Joining Aluminum to Steel Design Information Guide", Number E-11904 dated 6/78. Available from Dupont Detacouple Operations, 220 Gale Lane Suite 5, Kennett Square PA 19348.
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The Pan Pacific Hotel, San Diego, California, September 3-6, 1991.

Infrastructure Study in Shipbuilding: A Systems Analysis of U.S. Commercial Shipbuilding Practices

VA-1

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Zbigniew J. Karaszewski, Member, U.S. Department of Transportation

ABSTRACT

This report documents the results of the first phase of the Infrastructure Study in Shipbuilding (ISIS). The purpose for the first phase was to accurately document the current processes used to build commercial ships in the United States. These results have provided an increased understanding of the commercial shipbuilding process and have also provided a strategic planning tool capable of determining the length of time required to market, design, build and deliver a typical merchant ship in the united states.

The methodology used to document the shipbuilding process was IDEF. The resulting product was an IDEF, function model composed of 272 interrelated activities. A subset of seventy of these functions were analyzed with critical path methodology to produce a Gantt chart representing an atypical merchant ship acquisition program. Data was taken from a recently completed merchant ship program and used to establish an overall process duration for these seventy functions.

INTRODUCTION

The Maritime Administration (MARAD) and the Navy realize the importance of providing direction for existing maritime policy and R&D programs if the industry is to become globally competitive. The Infrastructure Study in Shipbuilding (ISIS) was conceived out of a mutually perceived need to create a strategic planning tool that could aid all sectors of the shipbuilding industrial base. ISIS represents a first step towards identifying actions required to help the United States shipbuilding industry become competitive in world markets. It is difficult, however, to formulate such an

industrial strategy without a firm understanding of the processes by which commercial ships are marketed, designed, built, and sold in the United States. The objective, therefore, for this initial phase of the project was to develop this understanding and to document it.

This study used a systems approach for analyzing and documenting the current U.S. shipbuilding process. While in the past two decades there have been a multitude of studies aimed at improving and modernizing individual shipbuilding functions, many of which have made significant contributions towards improving productivity, it is not clear that they have improved the industry's ability to produce a ship in a competitive time frame. The individual components have been dissected, analyzed, and improved, but the U.S. shipbuilding industry is still not actively competing in the global market.

The intent of this study is to explore an alternative approach for improving the competitive stance of the industry. This approach is centered on identifying those activities that drive the ship acquisition process from the standpoint of time. The key to reducing costs and gaining market share may lie in shortening or optimizing the overall process duration required to develop, market and manufacture merchant ships.

OVERVIEW OF THE SHIPBUILDING INDUSTRY

The ISIS study chose to define the industry as those shipyards, and the elements of the infrastructure that support them, that are currently capable of constructing large ocean-going ships (400 feet or longer). This definition is a subset of the one employed by the 1982 MARAD-sponsored shipyard mobilization base survey (SYMBA)[1]¹[2]. This sector of the industry currently consists of 20 shipyards which is approximately 50% of the number that were in existence in 1982[3]. Employment in this sector has declined from approximately 124,000 shipyard workers in 1982 to under 95,000 in 1990[3]. This segment of the industry currently accounts for 95 % of the industry's total work force[3]. Five of these twenty shipyards account for 95% of the dollar value of all existing naval ship construction contracts[3].

¹U.S. Dept. of Transportation, Maritime Administration, Washington, D.C.

²David Taylor Research Center, Dept. of the Navy, Bethesda, Maryland.

³Numbers in brackets designate References at end of paper.

The business base of the remaining shipyards, identified by the SYMBA survey, is shifting towards repair work. The 140 shipyards identified in 1982 by the survey were categorized as follows; 37 were classified as new construction, 49 were full repair, and 54 were limited repair facilities[3]. Repair yards represented 73 % of the shipbuilding industrial base in 1982. There were 116 facilities remaining in 1990 which were categorized as follows; 20 new construction yards and 96 repair yards[3]. Repair yards represented 83 % of the shipbuilding industrial base in 1990. These figures not only represent a 17% decrease in the total number of facilities between 1982 and 1990, but also highlight a demographic shift in the percentage of repair yards within the industrial base.

The industry, as defined by the 116 facilities currently in existence, employs a work force of approximately 100,000 people, of which 90% are directly supported by Navy programs[3]. This represents a loss of approximately 40,000 shipyard jobs since 1982[3]. Furthermore, it has been estimated that this shipyard work force reduction has resulted in the loss of approximately 100,000 jobs in the industrial sectors of the economy that support shipbuilding[3]. Even under the most optimistic naval ship procurement plan, the Navy has forecast that the industry will suffer additional work force reductions of approximately 20,000 shipyard workers by the end of the decade (reference Figure #1)[3].

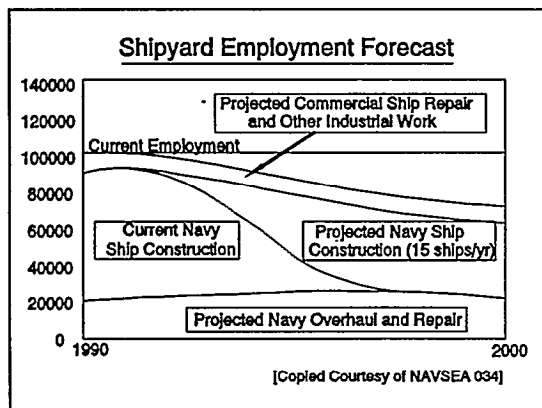


Figure #1 - NAVSEA Shipyard Employment Forecast

Industry Role in National Economy

The contribution of shipbuilding to the U.S. economy is relatively minor when compared to the contributions of other manufacturing industries. However, certain industries view shipyards as an important market for their goods and services, and consequently, for employment opportunities. In an economic input-output (I-O) analysis of shipbuilding prepared in 1982 for the Shipbuilders Council of America (SCA) and MARAD by Data Resources Inc., it was projected that by 1987 the industry's impact on the gross national product would be 0.50%[4]. This report went on to describe that out of the 100 industries used by the I-O analysis to represent the national economy, only seven depended upon the

shipbuilding market for more than 2% of their total production.

Nevertheless, a revitalized commercial sector of the shipbuilding industry, participating in sales to foreign buyers, could make a substantial contribution to the balance of trade. ISIS estimates show that by capturing 3% of the global shipbuilding market, or an average of 29 merchant ships per year (reference Figure #2), the U.S. industry would generate \$18.9 billion in new business (reference Figure #3) by the end of the decade[5][6]. This new business could sustain approximately 60,000 jobs within shipyards and their supporting industries (reference Figure #4)[5][6].

AWES* Forecast Calculations

AWES DWT forecast - 378,009,009 dwt by the year 2000.
 3% of AWES DWT-11,340,000 DWT-1,134,000DWT/year
 Average ship DWT in U.S. flag - Foreign Trade fleet:
 143 vessels involved in foreign trade.
 Total deadweight - 5,712,000.
 Average deadweight - 39,944.
 Number of ships per year - $1,134,000 / 39,944 = 29$ ships
 (* -Association of West European Shipbuilders)

Figure #2 - ISIS Analysis of AWES Forecast

Dollar Value Calculations

The foreign competition is capable of selling a cargo ship with a 36,000 ton displacement for \$40,00,000. U.S.
 $36,000 \text{ t} = \triangle = \text{LWT} + \text{DWT}$ where: $\text{LWT} - 1/3 \triangle = 12,000 \text{ t}$
 $\text{DWT} - 2/3 \triangle = 24,000 \text{ t}$
 $\$40,000,000. \text{ U.S.} / 24,000. \text{ DWT} = \$1,666.67/\text{DWT}$
 Estimated dollar value of 3% market share over 10 years:
 $1,134,000 \text{ DWT/year} \times \$1,667/\text{DWT} \times 10 \text{ years} = \18.9 Billion

Figure #3 - ISIS Dollar Value Calculations

Job Calculations

The foreign competition is capable of building a cargo ship with 36,000 ton displacement with 700,000 manhours (MH)*.
 $36,000 \text{ t} = \triangle = \text{LWT} + \text{DWT}$ where: $\text{LWT} - 1/3 \triangle = 12,000 \text{ t}$
 $\text{DWT} - 2/3 \triangle = 24,000 \text{ t}$
 $700,000 \text{ MH} / 24,000 \text{ DWT} = \text{approx. } 30 \text{ MH/DWT}$
 Shipyard jobs sustained by 3% of the world market:
 $30 \text{ MH/DWT} \times 1,134,000 \text{ DWT/year} = 34,020,000 \text{ MH/year}$
 $(34,020,000 \text{ MH/year}) / (1788 \text{ MH/manyear}) = 19,242 \text{ men}$
 Shipyard labor is approx. 1/3 of total labor required:
 Total jobs sustained by 3% market share - $3 \times 19,242$
 - approx. 66,060 jobs
 • Ref.[6] ** D.O.L Standard *** Ref.[4]

Figure #4 - ISIS Job Calculations

Industry Role in National Security

As the Cold War ends, it will be more necessary than ever to maintain a high level of reliable seagoing logistics capability. Until recently, mobilization planning and the requirements for U.S. ships followed some traditional Post-World War II scenarios. These scenarios primarily focused on a conflict between NATO and Warsaw Pact forces being fought on the European continent. They assumed that substantial material would be stockpiled close to the combat zones and that ports and bases would be fully secured prior to the commencement of resupply operations. The duration of any conflict was assumed to be short and attrition of merchant ships, whether from combat casualties or mechanical failures, was treated as a minimal concern. In the framework of this scenario, there was little requirement for shipbuilding within national mobilization plans.

In contrast, current events involving the erosion of the Warsaw Pact as a credible threat, and the anticipated reduction in deployed U.S. forces overseas, have radically changed the logistics picture, particularly with regard to sealift. A Congressional Budget Office (CBO) study in 1984 highlighted the importance of sealift in any extended engagement (reference Figure #5)[7].

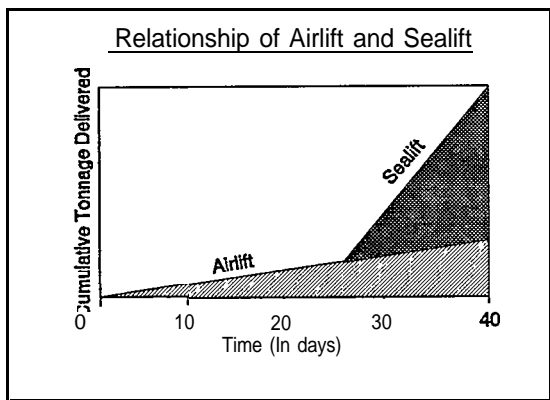


Figure #5 - Congressional Budget Office (CBO) Strategic Lift Assessment (1984)

The lessons from operations “Desert Shield” and “Desert Storm”, and Great Britain’s experience in the Falkland Islands War, suggest that current U.S. sealift assets may not be capable of sustaining forward-deployed forces in the existing threat environment[8][9]. In this new environment, the U.S. is not assured of vast supply stockpiles, nor pre-positioned assets, as was the case in Europe. The U.S. finds itself in a situation of extended and vulnerable supply lines, and its forces completely dependent upon airlift and sealift for re-supply. At a minimum, it is expected that our sealift capabilities including the Military Sealift Command (MSC), Ready Reserve Force (RRF), National Defense Reserve Fleet (NDRF), U.S. Flag merchant fleet, Effective U.S. Control (EUSC) ships and other available tonnage will be re-examined.

Global Market Trends

The shipbuilding industry currently faces major market changes that will have an impact on its future, well into the 21st century. Action is being taken to drastically reduce the government’s expenditures for military hardware. A clear result of this will be that the U.S. Navy budget for ship construction will decrease dramatically over the next ten years. Even under the current budget scenario, 95 % of the dollar value of naval ship construction contracts resides in only five shipyards[3]. The budgetary forecast indicates that in the future the Navy will not be able to sustain the industry at its current levels, let alone be the vehicle by which the industry becomes globally competitive. Coupled to this is the fact that the potential for the reemergence of previous forms of government subsidy has been virtually eliminated due to the recent Shipbuilders Council of America trade petition filed with the U.S. International Trade Commission. These factors indicate that the prospects are bleak for government support throughout the 1990s.

The shipbuilding industry can not depend upon the domestic commercial market to fill the void that will be vacated by the Navy. It has been forecast that the domestic market, even with the passage of the 1990 oil spill legislation requiring double-hulled tankers, would at best produce orders for only five to ten ships per year[10]. With the projected naval budget cuts, it will require orders for twenty-five to thirty-five merchant ships per year, by the end of the decade, just to maintain the industrial base at its current level[3]. This means that orders for fifteen to twenty-five ships per year must come from outside the domestic market.

An upswing in global merchant ship construction has been forecast for the 1990s. The number of ships that will be required to maintain the domestic shipbuilding infrastructure translates to three percent of the predicted world market. The definition of the world market used by this study was taken from a forecast prepared by the Association of Western European Shipbuilders (AWES) (reference Figure #6)[5].

Global Trends in Technology

Throughout recent history, most enhancements in shipbuilding and shipping technology have been fairly insignificant. However, there are several events, of revolutionary proportions, that are worth noting:

- 1) The development and construction of very-large and ultra-large crude oil carriers (VLCCs & ULCCs). This development was in direct response to changes in the distribution patterns of crude petroleum products. This market-driven innovation represented a major shipbuilding accomplishment, and led to a massive restructuring of the global industry. This restructuring was required because of the need to develop new facilities for the construction of these new ships which were much larger than their predecessors.

- 2) Similarly, although on a much smaller scale, the growing movement of liquified natural gas (LNG) by

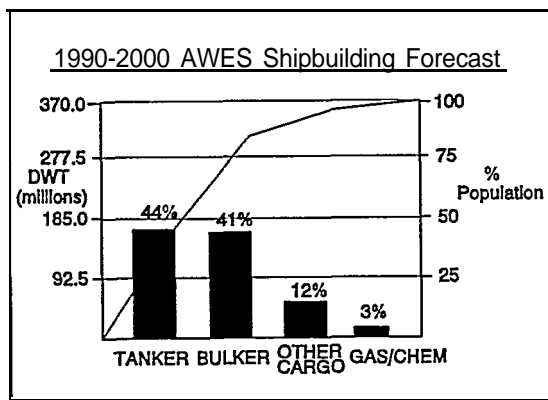


Figure #6 - Product Breakdown of AWES Forecast

ship required the application of complex technology by participating shipyards and precipitated the development of highly-specialized construction facilities.

3) The containerization of liner cargoes had tremendous impact upon the global shipping industry. The effect of this innovation is still being felt today in that it continues to be responsible for the development of cargo handling systems that are evermore intermodal in nature. However, containerization has not had a significant impact on ship construction technology.

At present, new hull forms for improved seakeeping are being developed for application to the passenger market. Other market innovations relate to advanced forms of cargo handling, packaging of goods and ship operations. International awareness of maritime issues concerned with ship safety and environmental protection will be steadily increasing throughout the 1990s. This new emphasis will most likely require technological innovation regarding ship structures and internal arrangements. However, the true extent of these market-driven requirements is, as of yet, unknown.

It should be stated that ship design innovation, however revolutionary, is largely irrelevant to shipbuilding competitiveness unless it has direct impact upon shipbuilding technology. A case in point, is that the development of VLCCs had tremendous impact upon shipbuilding technology, whereas, containerization had very little effect. Current trends in ship design technology appear to be emphasizing areas that will have little impact upon shipbuilding technology, e.g. smaller crew sizes, increased use of electronics and automation, and improved cargo handling methods. One notable exception is the modularization of passenger and crew accommodation spaces.

The evidence stated above suggests that the solution to the current lack of competitiveness of the U.S. industry lies outside of the realm of new technological breakthroughs. The technology trends noted here, although not significant with regards to how the ships of the future will be constructed, will nevertheless, impact heavily upon how these ships are designed and marketed. The process of

addressing the market's needs in an economical and timely fashion will become increasingly important. Lessons learned from each of these cases suggests that the industry must become evermore mindful of the future, and what it holds for ships and shipbuilding markets.

ISIS PROJECT DESCRIPTION

The first step in this study was to define the scope. To do that it was first necessary to describe the product, then identify who should be asked to participate in its development, and finally describe analytically all of the activities, and their interrelationships, that contribute to the development of the product. This process led to a definition of the shipbuilding infrastructure that was much broader than that of other recent studies. This expanded view of the industry was necessary to support the study's hypothesis that many of the recognizable problems in U.S. shipyards today originate at an early stage of the ship acquisition process. The ISIS effort has included in its examination industrial segments that heretofore have resided outside the boundaries of studies concerned with analyzing shipyard performance.

For the purpose of this study the shipbuilding infrastructure was defined to include all the participants that are either directly or indirectly involved in the current commercial shipbuilding process. Accordingly, ISIS has defined these participants to include: customer organizations, including shipowner, operator and leasing companies; ship design and systems engineering organizations; classification societies; financial institutions; vendors and subcontractors; government agencies; labor organizations; and education and training institutions. These participants are additional to the shipbuilding facilities and production-oriented engineering organizations traditionally used to define the shipbuilding industry.

This definition was more comprehensive than that found in existing references, but it was necessary in order to accurately model the entire shipbuilding process. Specifically, this definition of the shipbuilding infrastructure includes the customer, i.e. ship owner/operator, not just in his role as a consumer, but as a major player with the capacity to control and dictate the product's development.

This expanded definition also allowed for the examination of activities that precede the actual construction of a commercial ship, such as, the definition of the ship operating requirements, the evolutionary design process, and the development of the business relationship between the buyer (the shipowner) and the seller (the shipbuilder) as defined by the contract document. The contributions of the shipowner in the role of the customer are significant, and were taken into account in our description and modelling of the shipbuilding infrastructure.

The model of the industry's current capability, known as the "As-Is" model, focused on identifying through put inhibitors that encumber the acquisition process.

An analysis of non-subsidized commercial shipbuilding contracts established that the customer's primary objectives are a competitive price and a short construction duration. The customer's concern with quick delivery is primarily financial in nature. The money required to finance the construction of the ship must usually be borrowed on the open market.

Due to intense competition for available capital and the perception of risk on the part of the lender, ship financing packages usually have interest rates and terms that place a considerable burden upon the borrower. Every month that a ship remains under construction in a shipyard is another month that the owner must make the loan payment out of his own financial reserves. As a result, owners are under considerable financial pressure to get their ships operating and earning revenue as quickly as possible. This circumstance places a great deal of emphasis upon the length of time required to construct the ship. This study has attempted to address this concern via the creation and examination of a ship construction timeline. This timeline was based upon a recently completed U.S. merchant shipbuilding contract and utilized the ship acquisition functions identified by the IDEF₀ model.

Analysis of the shipbuilding infrastructure required a systems approach that could capture the complex logic and interrelationships among the various process activities, and also identify the influences of constraints that reside outside of the process flow. The method that was selected to accomplish this task was the ICAM Definition language, or IDEF. The origin of this methodology can be traced back to the Structured Analysis and Design Technique (SADT) developed during the 1960s[11]. These initial roots evolved into IDEF during the 1970s as a result of the Integrated Computer Aided Manufacturing (ICAM) program sponsored by the United States Air Force[12]. The purpose of this new approach was to create a series of process models that would determine where changes, within a particular manufacturing process, would result in improved productivity.

IDEF methodology is used to gain an understanding of the present condition of the system being scrutinized ("As-Is"). This understanding is achieved through the creation of a structured functional model that identifies activities and how they relate to one another. IDEF comprises three modelling methodologies which characterize the manufacturing process:

- 1) IDEF₀ is used to produce a "functional model", which is a structured representation of the functions of a system and of the information and objects which interrelate those functions.
- 2) IDEF₁ is used to produce an "information model" which represents the structure and semantics of information within the system.
- 3) IDEF₂ is used to produce a dynamic model which represents the time varying behavior of the process being analyzed.

IDEF consists of techniques for performing a systematic analysis of a process or series of integrated processes, and a graphical language for applying these techniques to produce function diagrams. IDEF diagrams are accompanied by text diagrams, which explain unique features of each individual graphic diagram, and a glossary which defines every term used in generating the graphical diagrams. The glossary acts as a project dictionary.

Only IDEF₀ was used during the course of the ISIS project. IDEF₀ models use as their building blocks individual functions, which are actions that have at least one input and one output. Functions transform their inputs into outputs by employing mechanisms (resources unchanged by the performance of the function), that are subject to certain constraints (rules, laws and basic business practices unchanged by the performance of the function) known as controls (reference Figure #7).

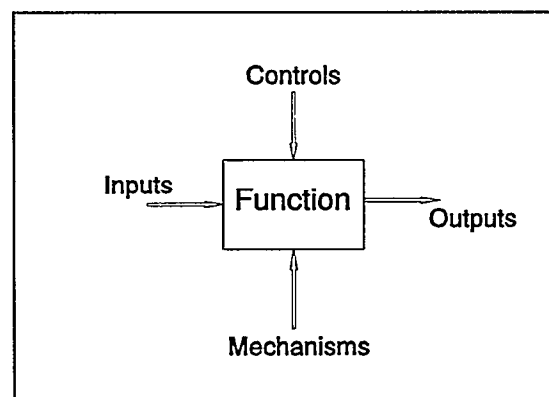


Figure #7 - Basic IDEF Mechanics

In parallel with the IDEF modelling effort, the ISIS team conducted a series of structured interviews with industry representatives. These interviews were intended to validate the analytic results of the IDEF modelling work, and provide expert testimony on the current state of the industry. A representative cross section of the shipbuilding infrastructure was contacted by letter to verify their willingness to participate in the project. Out of the respondents to this letter twenty-five candidates were selected. These candidates consisted of: ship designers (4); government agencies (4); equipment vendors (4); shipowners (4); shipbuilders (3); universities (3); regulatory agencies (2); and trade organizations (1). Information generated by these interviews was factored directly into the IDEF process model wherever possible. Financial institutions, maritime lawyers and organized labor unions were not included in this initial batch of interviews due to a lack of project resources. However, their input will be sought in the future.

Validation of the IDEF model was an important element of the project. An independent review of the entire model was made by each ISIS team member. After the review was completed, the model was applied to a recently completed ship construction project. The chosen vessel was the lead-ship of a series of products carriers built in the United States. Information and compliance were sought and provided by both the

owner and the builder of this ship. The functional breakdown of the ship construction process identified by the IDEF model was used to develop an acquisition timeline for this products carrier. This timeline was analyzed by Critical Path Methodology (CPM). A series of network diagrams and a Gantt chart were constructed for this products carrier using activities identified by the IDEF, model. The final step in the validation process was the review of the text report, IDEF model documentation, and the process timeline by the twenty-five industrial constituents interviewed by the project team.

IDEF models are hierarchial, and constructed from the top down, with each activity at one level decomposed in more detail at the next subsequent level. This process allows for each activity to be analyzed in progressively greater detail until some appropriate limit is reached. The limit which was arbitrarily set by the ISIS team at the onset of the modelling effort was to break the ship acquisition process down into approximately two hundred functions. This level of decomposition was seen as giving the project team a good initial understanding of the entire process, and allowed the team to plan for termination of the project within the recognized time constraint of nine months.

At the highest summary level of the model, the ISIS team examined the function entitled, "Produce a Merchant Ship" (reference Figure #8).

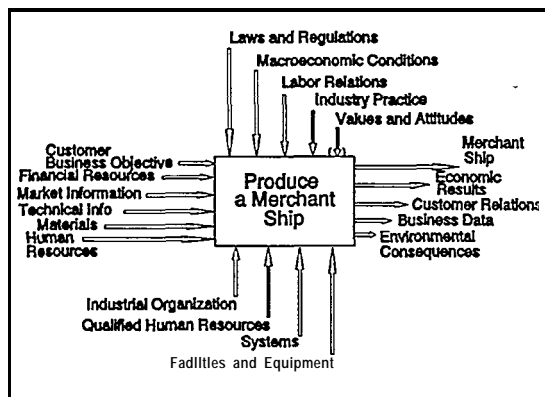


Figure #8 - IDEF Diagram A-0 - Produce a Merchant Ship

This top level function was decomposed into three distinct sub-functions:

- 1) "Develop a Ship Concept" - the activities associated with market analysis, customer requirements, concept design and preliminary design.
- 2) "Secure a Contract" - the development of a contract package, including contract plans and specifications, acquisition of capital financing, and the selection of a shipyard.
- 3) "Build and Deliver a Ship" - the detail design, material procurement, construction, testing, trials, and delivery of a merchant ship.

Each function together with its inputs, outputs, mechanisms and controls were documented in standard IDEF format down to a fourth level of decomposition. This fourth level of decomposition resulted in the identification of two-hundred and seventy-two total functions. The following section of the report discusses fifteen of the highest level functions. These functions are used to describe the entire ship acquisition process as defined by ISIS.

CURRENT SHIPBUILDING PRACTICE

This section of the report describes those functions identified in the IDEF₀ "As-Is" model, at the first and second levels of decomposition. These levels of decomposition define the ship acquisition process in terms of fifteen distinct functions. Each function is discussed in some detail and commentary supporting the existence and structure of each function has been provided.

Develop a Ship Concept

The "Develop a Ship Concept" portion of the model describes the processes that are used to perform an analysis of shipping transportation markets and translate this information into a set of ship requirements (reference Figure #9).

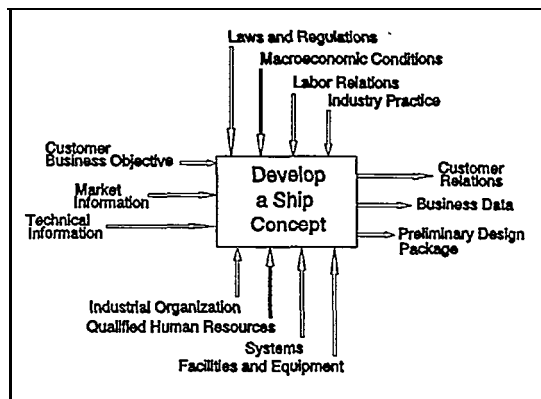


Figure #9 - IDEF Diagram A1 - Develop a Ship concept

These requirements are then used as a basis for the performance of both a conceptual and preliminary ship design, that establish the physical characteristics of a ship.

The process described here involves three distinct activities: 1) the identification of shipping opportunities; 2) the execution of a concept design that establishes the technical feasibility for developing a ship system that responds to the identified market opportunities; and 3) the preparation of a preliminary design that establishes the basic ship characteristics and the economic viability of different ship system alternatives.

The purpose of the "Determine Shipping Opportunities" function is to establish the need for new commercial merchant ships (reference Figure #10).

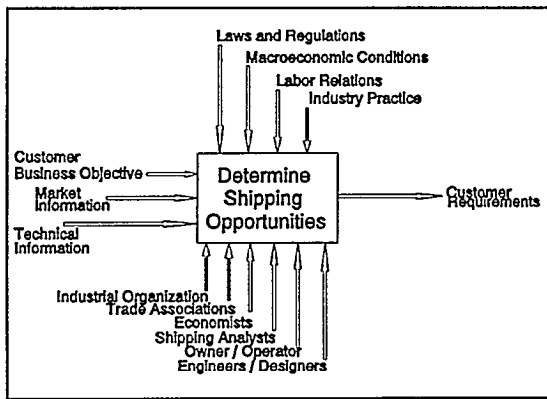


Figure #10 - IDEF Diagram A11 - Determine Shipping Opportunities

The first step is to analyze global transportation markets by studying forecasts of global waterborne cargo movements, existing merchant fleet capacity, fleet demographics and fleet economics. Market sectors are identified where the need for either new tonnage or replacement tonnage can be justified. The need for new tonnage is shown by a clear cut differential between the cargo hauling forecast and the fleet's available capacity. However, this same approach can also be used to justify whether existing tonnage should be replaced. This determination is generally supported by some form of market analysis, focused on a specific business opportunity. The requirement for replacement tonnage can usually be justified on a basis of either improved economics (lower operating costs, improved cargo hauling efficiency), or improved service to the customer (better intermodal connections, improved schedule performance, shorter shipping times).

The potential shipowner will compare his ship system concept against alternative transportation systems to determine if a ship will be preferable to either existing or planned forms of alternative service. The customer then determines how much he can afford to invest to address the market sector he has identified. The shipowner finally encapsulates this information into a set of customer requirements.

Market analysis at present is usually performed within a customer organization, and the results are not normally revealed to other participants in the ship acquisition process. Similarly, initial product development is usually performed by a team consisting of members from the customer's staff and contracted engineering firms. Shipyards, by not being involved in the market analysis or product development, cannot be proactive in executing aggressive marketing strategies or influencing aspects of the product's design that control its producibility[13]. U.S. shipyards have historically been excluded from the very activities that would allow them to develop the means for analyzing world markets and developing products that could be marketed directly to potential customers. As a result of this, U.S. shipyards, in many cases, find themselves waiting for customers to initiate the process.

The second function under the "Develop a Ship Concept" heading is "Perform Concept Design".

Concept design is the first step in the design process; its purpose is to translate a set of mission requirements into the approximate physical characteristics of a ship (reference Figure #11).

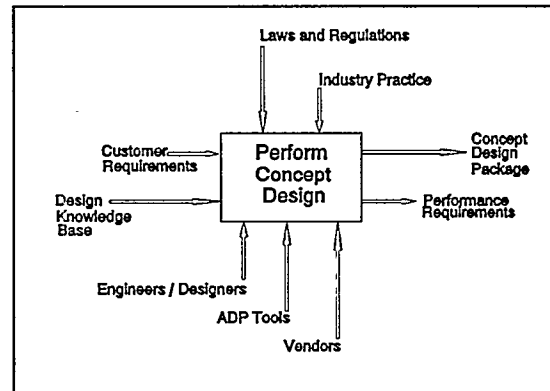


Figure #11 - IDEF Diagram A12 - Perform Concept Design

Concept design constitutes technical feasibility studies to establish one or more sets of ship characteristics, all of which meet the required speed, range, cargo cubic, and deadweight requirements defined by the customer. The concept design process also includes preliminary lightship weight estimates derived from empirical formulas, curves or experience. Variations in design configuration are generally analyzed in parametric studies during this phase to determine the most economical design solution. The selected concept design is then used for obtaining approximate construction costs, which often determine whether or not to initiate the next level of development, preliminary design.

The process of concept design encompasses several distinct activities: 1) empirical studies provide a quick and reliable starting point for the ensuing ship design. These studies generate an initial set of ship characteristics from existing curves, tables, algorithms, ship hull design series and technical databases; 2) parametric studies, include systematic analyses that are used to derive a set of optimum ship parameters that describe the ship's principal dimensions; 3) an approximate estimate of the ship construction cost consists of material, labor and overhead components; and 4) the finalization of the customer's requirements. Throughout this entire process, the results are compared against the customer's requirements and may call for changes to the existing requirements. However, if the proposed changes to the requirements are deemed as being too great it may be necessary to reiterate portions of the concept design process.

Any design process, particularly ship design, is a complex activity trying to satisfy many technical and economic requirements that are quite often conflicting in nature. At the initial stage of design, certain assumptions must be made regarding the behavior of the ship. These assumptions must be confirmed later as the design matures. Ship design is, therefore, an iterative process, proceeding from the early conceptual

design through successively more detailed steps. The free and unencumbered flow of information throughout this process is vital to achieving the desired result.

The final function under this heading is "Perform Preliminary Design". Preliminary design involves the development and refinement of the principal characteristics of a ship with greater precision than that required during the concept design stage (reference Figure #12).

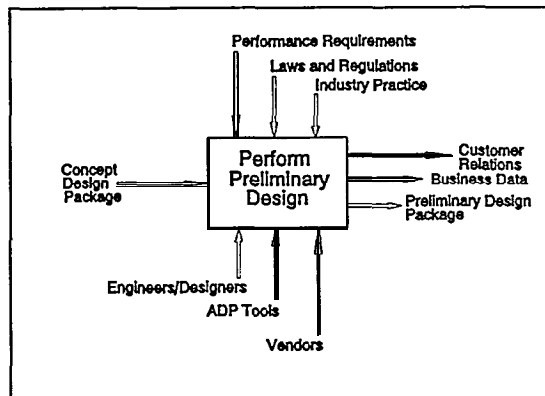


Figure #12 - IDEF Diagram A13 Perform Preliminary Design

These characteristics include principal ship dimensions, selection of hull form parameters, determination of the size and type of propulsion plant, development of a general arrangement and the hull's structural configuration. This design solution must *continue to* satisfy customer requirements such as deadweight, service speed, etc. In some cases, model testing may be required to substantiate the preliminary design results.

The process of preliminary design contains several individual steps: 1) a review of the concept design package, to verify that the owner's requirements have been properly translated into a ship definition that will serve as a starting point for the preliminary design; 2) a definition of ship geometry that involves the development of ship lines, capacity plans, hydrostatics, and trim and stability characteristics; 3) a definition of ship structure that involves the determination of preliminary scantling plans, computation of weights, and corresponding structural loads, 4) an estimate of the power requirements for the selected hull form; 5) the development of the general arrangement; and 6) the preparation of the preliminary design package.

This entire process is iterative. The preliminary design package should reflect the economic viability of the design, as well as the necessary technical considerations. The customer's concurrence with the preliminary design package is implied. The preliminary design process is generally self-contained and is not a highly visible component of the overall design process. The results of not having this early design work disseminated to all potential participants in the ship acquisition process have never been quantified. However, it is felt that this early lack of communication can only have a negative affect on the subsequent tasks within the process.

Secure a Contract

This second portion of the model describes the processes that translate the preliminary design package, which identifies a potentially profitable ship system, into a contract design from which a contract can be created and executed for the construction of a merchant ship (reference Figure #13).

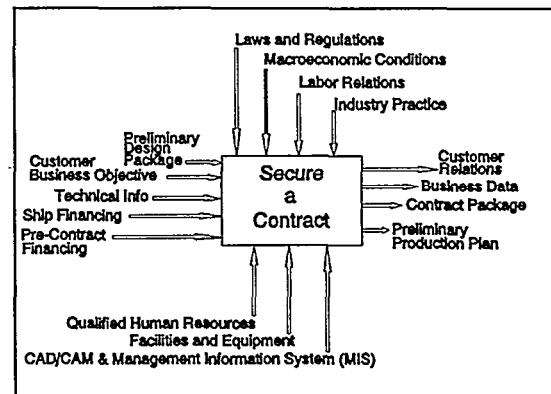


Figure #13 - IDEF Diagram A2 - Secure a Contract

The process of securing a contract involves five separate activities: 1) contract design, which defines the ship to be built in sufficient detail to allow the award of a construction contract; 2) the preparation of a solicitation package by the customer; 3) the arrangement of financing in support of the ship construction program; 4) the response of the shipyard(s) to the customer's solicitation; and 5) the selection of a shipyard and award of a contract.

The first function under this heading is "Perform Contract Design" (reference Figure #14).

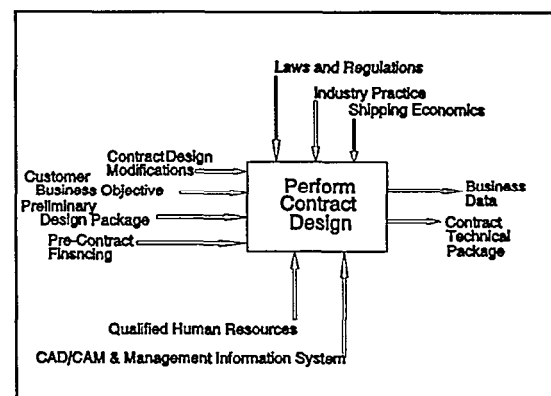


Figure #14 - IDEF Diagram A21 - Perform Contract Design

The contract design, i.e., the design of a ship in sufficient detail to support the award of a construction contract, is customarily performed in the U.S. by an independent naval architectural firm, that has been retained by the customer. This arrangement has made contract design, along with its related deliverables, relatively independent and self-contained. The contract design process is comprised of

four major activities: 1) performance of system studies; 2) the preparation of a contract technical package; 3) the obtaining of preliminary regulatory approvals; and 4) a management activity which involves the planning, resource allocation, performance measurement and reporting steps that are generally associated with managing a ship design effort.

A naval architectural firm is normally used to develop the contract design in accordance with the requirements of the customer. As a result, shipyard contributions with respect to producibility or sources of supply are not, in most cases, solicited or incorporated into the design at this stage. This omission tends to make the resulting ship design more expensive, and less widely applicable to the needs of other domestic or international customers.

The second function under this heading is "Prepare Solicitation Package". This function represents the process that the customer uses to initiate communications with one or more shipyards, and their suppliers, for the purpose of eliciting proposals based upon the completed contract design (reference Figure #15).

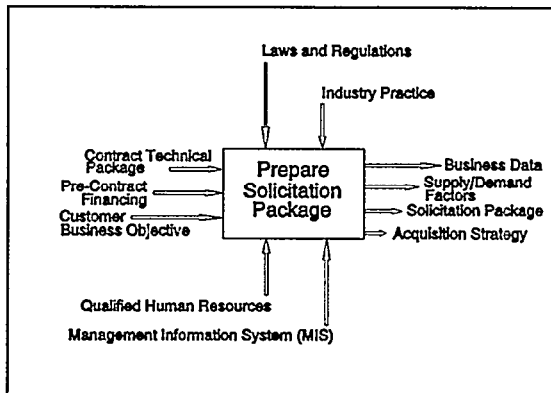


Figure #15 - IDEF Diagram A22 - Prepare Solicitation Package

It is, therefore, necessary to include in the solicitation a technical description of the ship that is as complete as possible at the time the solicitation is let. The following activities are performed by this function: 1) an assessment by the customer of the shipbuilding market resulting in the creation of a set of terms and conditions to be incorporated into the construction contract; 2) the assembly of a solicitation package; 3) the preparation of a bidders list; 4) the distribution of the solicitation among those organizations identified on the bidders list; and 5) the management of the solicitation process.

It is customary for the shipowner's staff to be heavily involved in this function. Shipowners have in the recent past exhibited very little confidence in the level of understanding that U.S. shipbuilding organizations have with regards to ship operations. As a fail-safe measure some of these organizations maintain sizeable technical staffs to insure that this knowledge is incorporated into the acquisition process. The existence of a solicitation package, and the

implication that bids are solicited by a customer from more than one shipyard, is indicative of the problem that U.S. shipyards face regarding their product development and marketing strategies. Elsewhere in the world, shipyards have become far more active in defining markets and products; in comparison, U.S. yards have come to employ a more reactive approach.

"Arrange Financing" is the third function under this heading. This function involves the process of obtaining the necessary financing to enter into a construction contract with a shipyard (reference Figure #16).

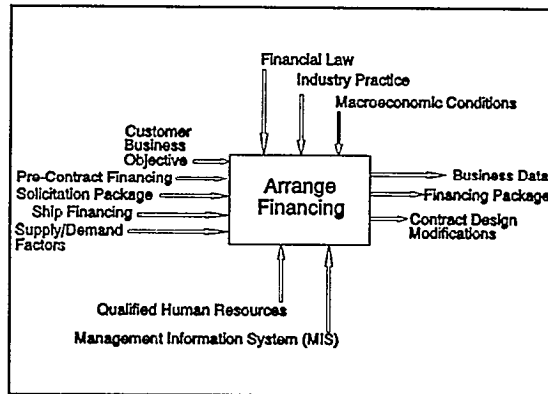


Figure #16 - IDEF Diagram A23 - Arrange Financing

The need for this activity arises from the fact that customers, in general, do not have the financial resources available to invest in a major asset such as a ship, and must rely on existing forms of debt financing. The use of highly-leveraged debt financing is most attractive to operators and their creditors, especially when government loan guarantees are available. This series of circumstances has created a relatively aggressive market for the creation of new financing instruments for ships within both the financial and ship operations communities.

The principal activities accomplished by this function are: 1) an independent assessment of the financial viability of the project; 2) an identification of potential sources of capital; 3) the creation of a capital-borrowing structure; and 4) the attainment of firm commitments from each source of capital. Financing as perceived in this model involves a set of negotiations between the shipowner and the financial institution of his choice.

This is the point within the acquisition process where the economics of shipbuilding intersect with those of the global financial community. U.S. shipyards have not recently been involved, to any great extent, in the financial arrangements supporting the sale of their products. This is in direct contrast to their foreign competitors, who are accustomed to arranging financing for their customers[14]. Obviously, government policies, particularly those involving taxation, supports, and subsidies have a significant impact[15]. Much work needs to be done in determining a sound methodology for creating financial packages for merchant ships in the United States. Once

the process is understood and clarified the government could be used to help facilitate the policy changes that would be required to make the process attractive to potential customers.

The fourth function in this progression is "Prepare Shipyard Response". This function describes the process by which a shipyard will respond to the solicitation distributed by the customer (reference Figure #17).

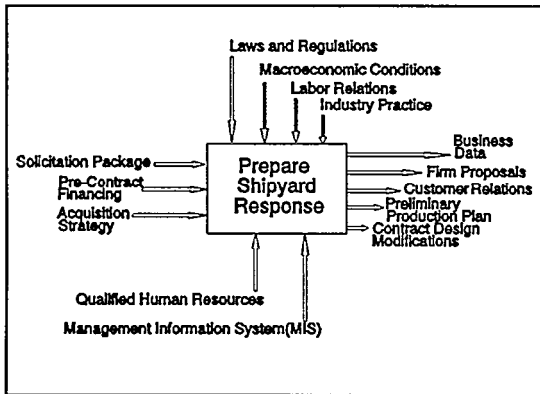


Figure #17 - IDEF Diagram A24 - Prepare Shipyard Response

The following activities are included under this function: 1) a shipyard analysis of the solicitation requirements; 2) the preparation of a cost estimate; 3) the preparation of a formal response to the solicitation; 4) preliminary discussions between the customer and each responding shipyard; and 5) an overall proposal management activity.

The process described here is less formal than that employed by the Government, but is nonetheless competitive. Customers develop preferences for shipyards over time (hence the importance of customer relations). But as in any profit-driven enterprise, customers always seek to lower both investment and operating costs wherever possible.

The fifth and final function under this heading is "Select a Shipyard". This function involves the steps taken by the customer to select a shipyard, once preliminary discussions with one or more of these yards have yielded a set of firm offers (reference Figure #18).

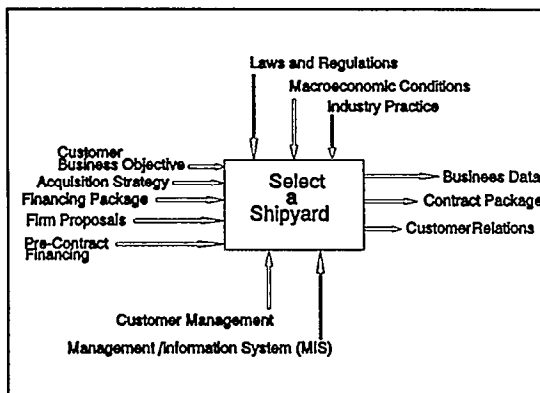


Figure #18 - IDEF Diagram A25 - Select a shipyard

These steps include: 1) the establishment of selection criteria; 2) the evaluation and ranking of each shipyard proposal; 3) final negotiations with the highest ranking shipyard; and 4) the management of the selection process by the shipowner in accordance with his own cost and schedule requirements.

This task assumes some flexibility in the evaluation process. Where shipyards are offering to construct the ship as described in the original solicitation, the selection criteria will involve primarily price and delivery, with some consideration of quality, prior performance, customer relations, etc. However, the process as described allows for each offerer to submit a modified design or approach that they feel is superior to the one that was described in the solicitation package. This added degree of freedom in the proposal process will require the customer to evaluate the benefits of each design variation on a separate and perhaps unique basis.

Build and Deliver a Ship

This third and final group of functions describes the process whereby a shipyard and its suppliers construct and deliver a ship (reference Figure #19).

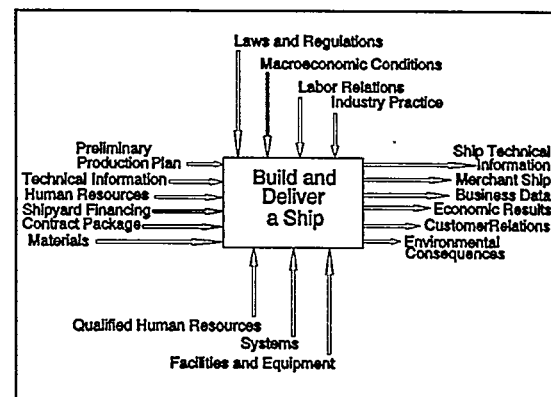


Figure #19 - IDEF Diagram A3 - Build and Deliver a ship

This portion of the procurement process starts with the execution of the construction contract and concludes with the delivery of the ship to the customer. In contrast to the preceding activities, the shipyard is primarily in control of this stage of the acquisition process. In addition, considerable contributions to this portion of the process emanate from supplier and vendor organizations. Construction and delivery of a ship involves four major functions: 1) management of the overall shipyard operation; 2) preparation of a detail design; 3) the procurement of all material and equipment that will be consumed or installed on the ship; and 4) the fabrication, assembly and testing of the ship.

Even though vendors and suppliers are usually subcontracted by the shipyard, and are therefore subject to the shipyard's project management, they must still be given ample representation within the process model. This is justified due to the critical impact that material availability has on the entire construction process. In some situations, the supply of outside components and labor is so significant

that it shifts the shipbuilding emphasis from that of being a fabricator to that of being an assembler.

The first function under this group is "Manage Construction Operations". This function describes the management process associated with the execution of a shipbuilding contract, and reflects the observation that program planning is a relatively centralized process within the shipyard (reference Figure #20).

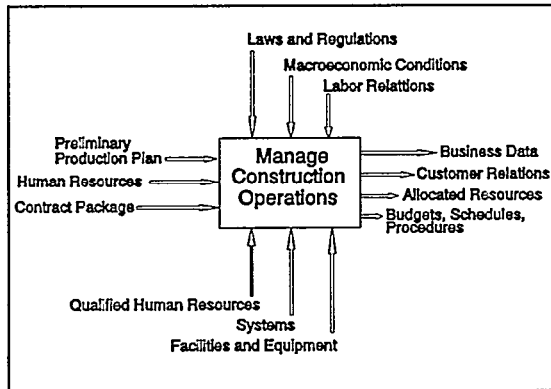


Figure #20 - IDEF Diagram A31 - Manage Construction operations

The following management activities are performed under this function: 1) contract administration, which includes three separate sub-functions: a) the overall process of management control implied through the adherence to the shipbuilding contract; b) the definition of specific requirements placed upon the shipyard organization by the contract; c) the maintenance of customer relationships throughout the contract period and beyond; 2) the identification of resource requirements; 3) preparation and maintenance of Program schedules; and 4) preparation and implementation of required procedures.

The shipyard management and planning activities for a specific contract are relatively centralized, although shop planning activities do introduce some decentralized planning functions. This series of tasks also describes the way in which human resources are employed within the industry. Specifically, there exists a small management cadre, and a large blue-collar construction work force. The blue-collar work force's strength lies in its job experience. In recent years, it has been increasingly difficult to retain, find, or replace highly-skilled workers who are leaving the industry through all of the normal channels of attrition. Training programs within the industry have not kept pace with the recent demographic changes within the work force [16]. There is a need for innovative human resource development strategies that will improve both white-collar and blue-collar productivity [16].

The second function under this heading is "Develop Detail Design". Detail design is intended to accomplish a number of goals including precise definition of the ship configuration, definition of all material requirements, and the preparation of manufacturing-support information. In addition, specific information derived during the detail design is provided to the customer for his use in connection

with the operation and maintenance of the ship (reference Figure #21).

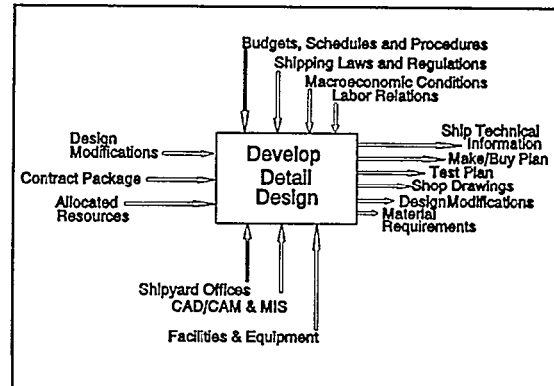


Figure #21 - IDEF Diagram A32 - Develop Detail Design

These goals are reflected in the following activities that comprise detail design: 1) final definition of the ship as a system; 2) design of ship systems and components; 3) approval of the design; 4) development of a production approach; and 5) Preparation of shop drawings.

While the detail design process is important to a successful shipbuilding program, it has a serious defect: it is effectively isolated from the earlier design efforts. As a result of this isolation, the detail design is executed without access to earlier design products, which can result in additional, and sometimes redundant, design effort. In addition, the detail design tends to be conservative, since innovation is not encouraged at this advanced stage of the design process. If the detail design is performed by an engineering firm outside of the shipyard, another problem can emerge. In this situation, the detail design can proceed independent of the shipyard's production approach, thereby resulting in a lack of integration into the design of producibility considerations unique to the shipyard and its manufacturing processes. This can severely effect the yard's ability to deliver the vessel on-time.

The third function under this heading is "Procure Material". This function describes the process of acquiring all of the material and equipment required to construct and outfit the ship (reference Figure #22).

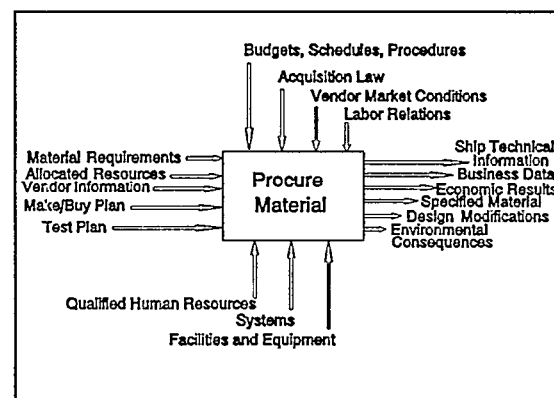


Figure #22 - IDEF Diagram A33 - Procure Material

This is a broad-ranging definition, in that the production work performed by supplier organizations has also been included within the process model structure. There are four parts to this function: 1) the definition of procurement requirements; 2) the preparation and issuance of purchase orders; 3) the execution of the purchase orders by the suppliers; and 4) the inspection and storage of the received material within the shipyard, and its release to production.

The U.S. shipbuilding industry's approach to the selection of vendors and subcontractors is constrained by two competing forces. On the one hand, politics encourage shipyards to buy material and components locally, and normally they are happy to do this, except for major cost items. On the other hand, the industry has been forced by the government, in certain cases, to select only domestic sources of equipment on a cost competitive basis. These two concepts of "Buy American" and lowest "qualified" bidder have severely inhibited the industry's ability to develop long-term sources of supply. Vendor-related delays that can result from inconsistent use of vendors have the potential to severely affect the construction duration. However, it would require considerable further study to substantiate this hypothesis.

The decline in world shipbuilding output over the past ten years has been accompanied by a related decline in the number of suppliers capable of furnishing marine equipment and material. This market-driven reality has made it more difficult to acquire needed material in a timely and economic fashion. However, this problem is not solely an American problem, as it is currently shared among all of the major shipbuilding nations. Lessons can be learned from our foreign competition regarding the development of efficient supplier networks. In an environment of reduced availability, it will become increasingly important to take a global approach towards the problems associated with material procurement[17]

The fourth and final function under this heading is "Produce Ship" (reference Figure #23).

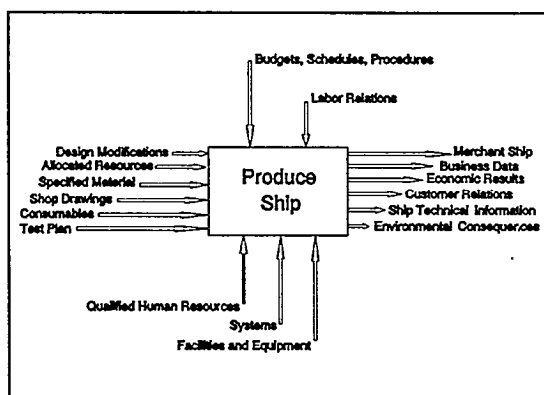


Figure #23 - IDEF Diagram A34 - Produce Ship

The following steps have been included under this function: 1) shop planning; 2) fabrication of parts; 3) hull erection; and 4) final outfit installation and testing.

This includes all post-launch outfitting and testing activities. These tasks terminate with the delivery of the completed ship to the customer.

The process described here assumes that all production work, including fabrication, installation and testing is performed by a single shipyard. This is an approach that has been customarily employed by the U.S. shipbuilding industry. However, the benefits of large-scale subcontracting among shipyards offers an opportunity to achieve significant reductions in contract duration. There is a subsequent requirement for an increased planning and control effort to facilitate an increased level of off-site manufacturing. The trade-offs and merits of expanding current shipbuilding subcontracting practices need to be examined in greater detail. In addition, the degree of integration between material specification, material procurement, shop drawing preparation, and shop planning activities is worthy of further examination.

TIMELINE DEVELOPMENT & CRITICAL PATH ANALYSIS

There were several project-related reasons for developing a timeline. The IDEF methodology does not establish predecessor or successor relationships between activities. Its main purpose is to identify activities and the critical information, resources and constraints necessary to perform these activities. However, project-related reasons made it necessary to interrelate these activities on the basis of time so an analysis of the overall process duration could be made.

The project team needed a medium that could communicate the results of the project to an audience that did not necessarily possess a working knowledge of the IDEF methodology. Since most ship construction projects in the U.S. employ some form of Critical Path Methodology (CPM) when developing their engineering and production schedules it was decided that the timeline should be constructed using this methodology[18]. The Gantt chart resulting from the critical path method analysis (reference Figure #24) is supported by CPM network diagrams showing the interdependencies between the activities (reference Figures #25-#27)[19]. Analysis of these activities has identified several areas where the consumption of time appears to be a problem.

The "As-Is" model's third level of decomposition was selected for analysis. This was the level of detail selected for representation in the Gantt chart referenced above. This level of detail represented seventy activities. There was a desire to have a compact mechanism for presenting the initial results of the ISIS project. This desire became the overriding consideration in the selection of the number of activities to include in the process timeline. A quantity of seventy activities seemed realistic when based upon the available ship production information. Secondly, for purposes of comparison with foreign shipbuilders and other domestic manufacturers this number of functions was viewed as being supportable.

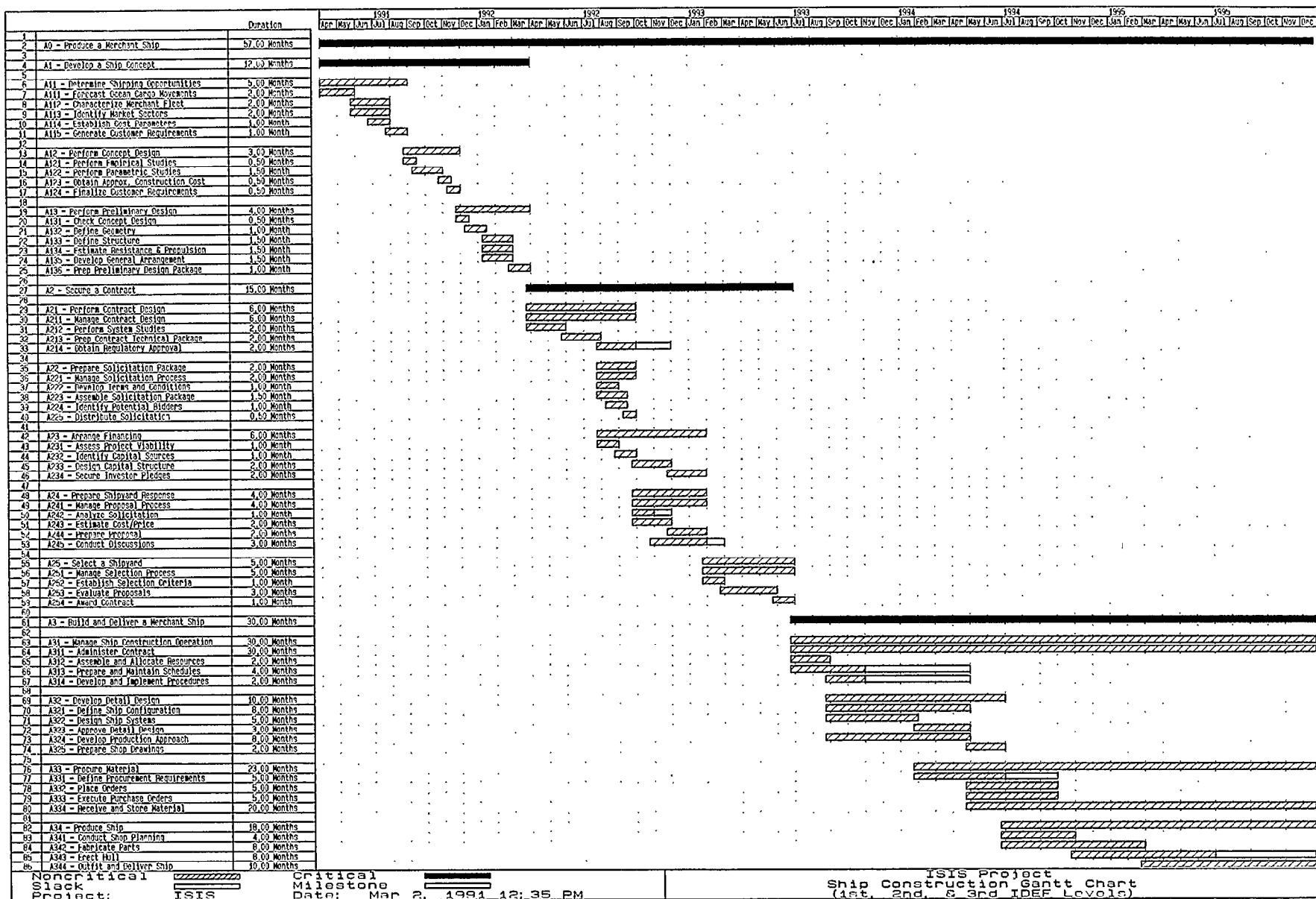


Figure #24 - Gantt Chart (1st, 2nd, & 3rd IDEF Levels)

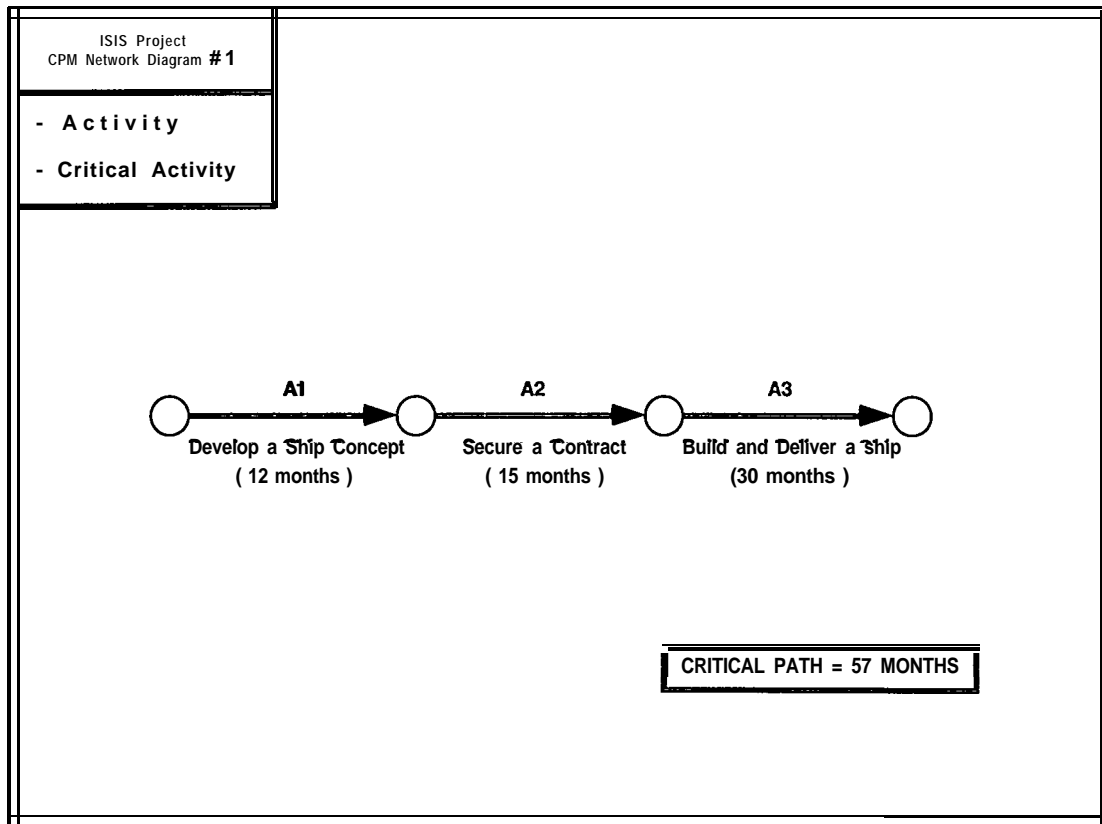


Figure #25 - CPM Network Diagram #1 (1st IDEF Level)

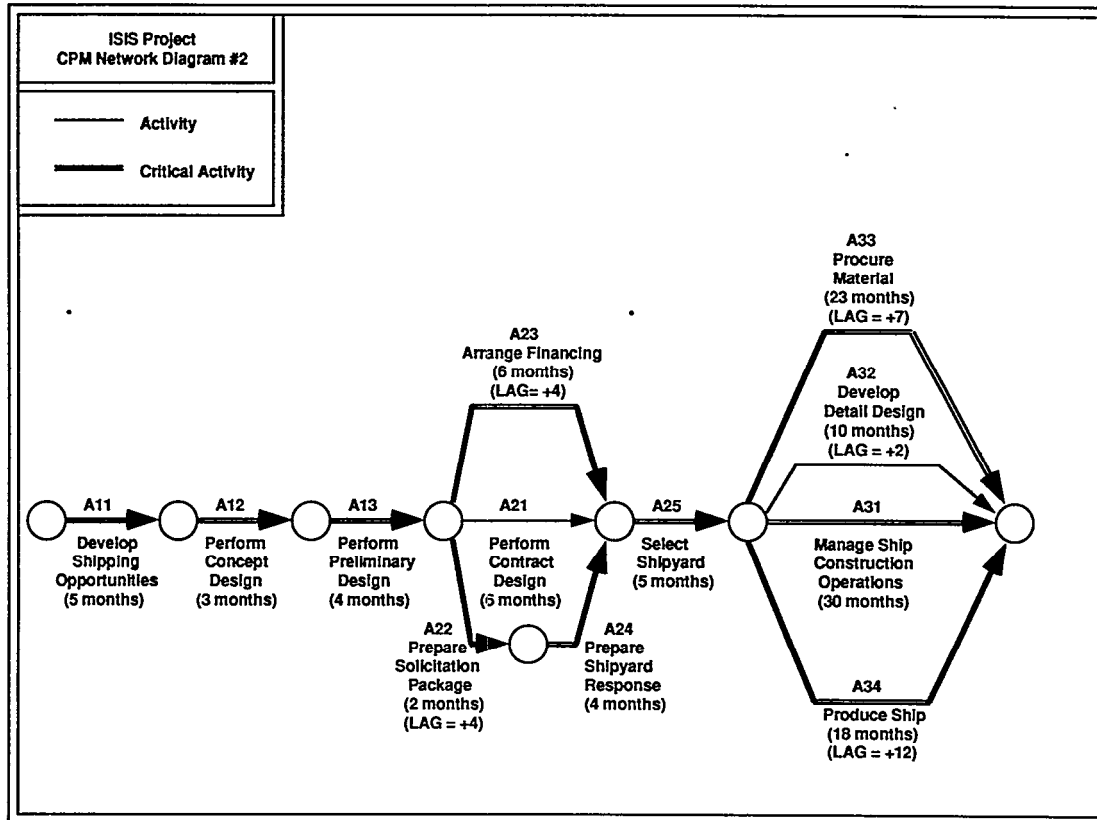


Figure #26 - CPM Network Diagram #2 (2nd IDEF Level)

ISIS Project CPM Network Diagram #3

- Activity
 - - - - - Dummy Activity
 - Critical Activity
 MAC - Months After Contract
 N/S - Not Shown

A111 Forecast Ocean Cargo Movements
 A112 Characterize Merchant Fleet
 A113 Identify Market Sectors
 A114 Establish Cost Parameters
 A115 Generate Customer Requirements
 A121 Perform Empirical Studies
 A122 Perform Parametric Studies
 A123 Obtain Approximate Construction Cost
 A124 Finalize Customer Requirements
 A131 Check Concept Design
 A132 Define Geometry
 A133 Define Structure
 A134 Estimate Resistance & Propulsion
 A135 Develop General Arrangement
 A136 Prepare Preliminary Design Package

A211 Manage Contract Design (N/S)
 A212 Perform System Studies
 A213 Prepare Contract Technical Package
 A214 Obtain Regulatory Approval
 A221 Manage Solicitation Process (N/S)
 A222 Develop Terms and Conditions
 A223 Assemble Solicitation Package
 A224 Identify Potential Bidders
 A225 Distribute Solicitation
 A231 Assess Project Viability
 A232 Identify Capital Sources
 A233 Design Capital Structure
 A234 Secure Investor Pledges
 A241 Manage Proposal Process (N/S)
 A242 Analyze Solicitation
 A243 Estimate Cost/Price
 A244 Prepare Proposal
 A245 Conduct Discussions
 A251 Manage Selection Process (N/S)
 A252 Establish Selection Criteria
 A253 Evaluate Proposals
 A254 Award Contract

A311 Administer Contract (N/S)
 A312 Assemble and Allocate Resources
 A313 Prepare and Maintain Schedules
 A314 Develop and Implement Procedures
 A321 Define Ship Configuration
 A322 Design Ship Systems
 A323 Approve Detail Design
 A324 Develop Production Approach
 A325 Prepare Shop Drawings
 A331 Define Procurement Requirements
 A332 Place Orders
 A333 Execute Purchase Orders
 A334 Receive and Store Material
 A341 Conduct Shop Planning
 A342 Fabricate Parts
 A343 Erect Hull
 A344 Outfit and Deliver Ship

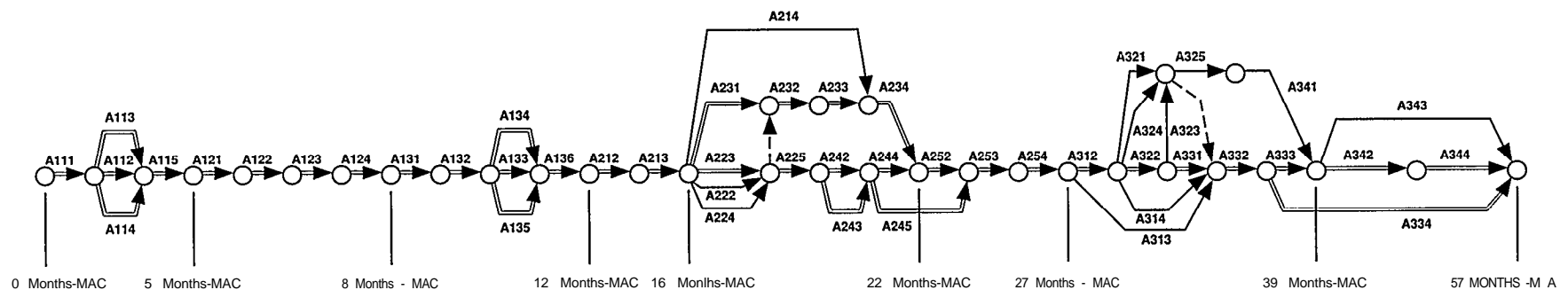


Figure #27 - CPM Network Diagram #3 (3rd IDEF Level)

The validation of the IDEF model required a recently completed ship construction project. This project had to satisfy some basic criteria. The ship had to have been constructed in the United States. The project had to have been completed within the last ten years. The ship was to have been built for a private customer, and financed with a minimum of government involvement. Finally, if possible, the ship should have been constructed for international trade.

The project team was able to obtain information about a ship construction program that met all of the above criteria, except for the international trading requirement. Information was obtained directly from the shipowner. This information was made available only after the approval of the shipbuilder had been given. The selected ship is a products carrier (42,000 DWT) built for a U.S. flag operator. The physical dimensions of the ship are approx. 194 m (640 ft.) long X 32.3 m (105 ft.) wide X 11.6 m (38 ft.) draft. The ship is single screw with a 17,000 bhp low speed diesel power plant and a required service speed of 16 knots. The ship was competitively bid among six domestic shipyards. The construction contract for this ship was awarded to a major U.S. shipbuilder. The ship was privately financed and received no form of government subsidy or loan guarantee.

It was determined that this ship had a critical path duration of 57 months. The three major components of this ship's acquisition timeline, are identified by the 1st level of the IDEF model:

Develop a Ship Concept	12 months
Secure a Contract	15 months
Build and Deliver a Ship	30 months

Total Ship Acquisition Duration	57 months

It should be understood that in this case the shipowner performed the "Develop a Ship Concept" portion of the process. It could therefore be argued that there was no market-driven time constraint on the performance of this front-end acquisition task. This raises the possibility that the 12-month duration is an overestimate of what the task would take if it was performed by either a shipyard or a design firm. Since the ISIS project team had access to information pertaining to only this shipbuilding project there are no grounds for a counter argument against this claim.

However, several questions must be asked. Why is the manufacturer, in this case the shipbuilder, not involved in the early stages of product development? Would the shipbuilders' active participation in product development reduce the time required to not only develop a ship concept design, but also shorten the subsequent phases of the ship acquisition process? What can be done on the part of government, industry and academia to facilitate and implement changes that would enhance the product development cycle for ships?

It was determined that the second portion of the acquisition process, "Secure a Contract", took 15 months to accomplish. In this particular case the capital resources required to fund the ship acquisition were made available by the shipowner. The fact that the shipowner, or shipyard, did not have to locate and acquire sources of capital on the open financial market suggests that the estimate of duration for this portion of the process may be somewhat optimistic. However, any estimate as to the impact on duration of procuring financing on the open market would be purely speculative at this time.

Questions must be raised regarding the contracting process and its identified participants. Is a contract design stage necessary if a standard product development cycle is developed and implemented for ships? Why is the customer responsible for soliciting bids for his own ship? Why is the customer responsible for securing capital financing for his purchase of a ship? Why is the shipyard not seeking out potential customers far in advance of this contracting stage, thereby, eliminating the need for a formal solicitation, proposal, and shipyard selection process?

The third and final portion of the acquisition process, "Build and Deliver a Ship", was determined to take 30 months to complete. There were no customer-related anomalies to this portion of the process as there were with the two previous portions. There is, however, one striking observation to be made. Out of the 30 months required to complete the ship acquisition, after the award of the construction contract, only 18 months are required to actually construct the ship.

This observation suggests that it takes 12 months for the shipyard to plan, identify, and procure the material required to support the start of construction. Should not a basic build strategy, with an accompanying material requirements plan, be developed prior to contract award? Would the adoption of standard components, materials and interim products expedite the detail design process? Would a more aggressive approach to "make/buy" decisions allow the shipyard to retain the higher value-added work while helping to shorten the construction duration? Should more emphasis be placed on material lead times, and on a vendor's ability to deliver material as required by the production schedule, rather than on material costs?

These questions have been raised in hope that the industry will recognize where problems exist within the current ship acquisition process and start addressing these problems by rallying existing maritime research and development assets. It is important for all members of the shipbuilding infrastructure to be made aware of these weaknesses. Action taken by any one member of the infrastructure without the direct involvement and support of the other members will, at best, lead only to parochial and marginally effective solutions for the industry's problems. Only through knowledge can strategies be developed that will strengthen the existing infrastructure. Unless government, industry, and academia work together to

analyze these problems, there will be no consensus as to the action required to solve them. The ISIS team has attempted, through this report, to raise the awareness of where new emphasis for policy, product, and process improvements should be placed in the immediate future.

CONCLUSIONS & RECOMMENDATIONS

The U.S. shipbuilding industry is currently in the midst of a quiet revolution; slowly moving away from traditional shipbuilding methods towards a more modern approach that could be termed ship manufacturing. However, many hurdles still exist, and the effort to date in the U.S. has been limited to piecemeal approaches by individual organizations catering to their own in-house requirements. Sharing of information among members of the shipbuilding infrastructure has been a problem that can be attributed to the strong competitive nature of the existing marketplace. The National Shipbuilding Research Program (NSRP) has improved the accessibility of information dramatically during its life span; however, there still remains a need for a comprehensive “battle plan” for the industry as a whole.

The ISIS team has identified several areas of the existing ship acquisition process that require immediate attention. The first area involves the infrastructure’s ability to create and implement a methodology that will develop commercial products on the basis of sound market analysis. The next area concerns the infrastructure’s knowledge of how to structure a capital financing package on behalf of a customer. The final area addresses the need for new approaches towards the identification and procurement of material and equipment.

Within the “Develop a Ship Concept” portion of the process there are several relevant observations. There appears to be no obvious reason as to why the industry cannot immediately begin to cultivate commercial market analysis and product development expertise within its own ranks. Product development strategies for the U.S. shipbuilding industry can be developed by analyzing strategies that have been successfully executed by both domestic and international manufacturing concerns. It is postulated that this expertise should reside within the manufacturing sector of the infrastructure. This would guarantee a strong alignment between each manufacturing firm’s capabilities and potential markets. Motivation and innovation on the part of market analysts and product developers can best be instilled when they have a direct stake in the outcome of their efforts. The continuous nature of this task also supports the need for the manufacturer to develop a cadre of in-house talent to address this challenging aspect of the ship acquisition process.

This observation is based upon the IDEF₀ modelling of the front-end acquisition functions. The IDEF₀ functions All - “Determine Shipping Opportunities”, A12 - “Perform

Concept Design” and A13 - “Perform Preliminary Design”, are currently performed by different mechanisms. In A11, there appears to be no domestic organization, either public or private, that currently has resources capable of monitoring the global shipbuilding market and matching U.S. shipbuilding talent with identified market niches throughout the world. This activity is currently performed by market consultants for individual clients on an “as-needed” basis.

In IDEF₀ functions A12 and A13 there is no single mechanism that can take either an internally, or externally, generated market analysis and use it to develop a commercial ship, and, once developed, openly pursue potential customers. The dysfunctional aspect of these activities appears to be that there are too many participants involved and that each of them has little responsibility or authority to control the overall product development process. It is proposed that there be a central repository established within the infrastructure where such information and analysis could be generated and maintained. This repository could be supported via a form of governmental and industrial cost-sharing.

The “Secure a Contract” portion of the process has become an important contributor to the total process duration. The reason for this may be that the customer has been responsible for all the activities under this heading, by acting as a “general contractor” in order to ensure a satisfactory outcome to the acquisition process. This not only takes a great deal of time and effort on the part of the shipowner but also lengthens the time required for post-contract award activities. The customer clearly does not belong in this position.

The complexity and length of the ship acquisition process affords an opportunity for many individuals within the infrastructure to participate. However, no one participant appears to dominate the overall process. The lack of a central figure for controlling, monitoring and documenting the acquisition process has created a situation where the customer tends to direct the entire process. The customer attempts to direct by exercising the only instrument available, namely, the contract document.

The unconscious result of this action on the part of the customer, however well intended, further denigrates an already complicated and lengthy process. Many of the activities under this heading could be shortened or eliminated entirely if a normal product development cycle were to be adopted by the industry. Reassigning responsibilities seems to be the first step needed to improving this portion of the ship acquisition process. Only after this is accomplished would a re-assessment of the sequence of events have any chance of improving the overall process duration.

The structuring and execution of capital finance packages may also be part of the problem within the “Secure a Contract” portion of the model. It is obviously an area where the industry must make a strong commitment towards becoming self-reliant.

Current trade negotiations between the U.S. and its trading partners portend a future where government subsidies will not be allowed. This will eliminate, or, at a minimum, severely restrict government programs currently used to provide funds or guarantee loans for new ship construction. It is imperative that the industry develop working relationships with private sources of capital as soon as possible. The industry must attempt to identify members of the financial community that will help them to understand the financing process.

The problems that arise during the last portion of the process, "Build and Deliver a Ship," can be accurately predicted by a careful assessment of all the activities preceding the contract award. The shipbuilder has been isolated from the market assessment and product development activities and may therefore have the contract package as his only source of information. In most cases this results in work required to support manufacturing not starting until the contract has been awarded. Since the ship has most likely been designed by someone other than the shipyard, there is little opportunity or incentive for the shipyard at this late date, to influence aspects of the design that might improve its producibility.

The fact that, up to this point, the shipyard has had limited exposure to the ship design forces it into a "cold start" regarding numerous activities such as detail design, scheduling, planning, and material procurement. The result of this can be shown by referencing Figure #24 where it takes twelve months from contract award until the start of fabrication. The lack of industrial standards, regarding engineering design and materials, simply compounds this problem.

This situation leads to a massive engineering and purchasing effort on the part of the manufacturer. This effort is made more difficult by the customized nature of the product, and by the fact that the manufacturer has had little opportunity to analyze the design prior to contract award. Added to this are the constraints placed upon the shipyard by the construction contract and the inherent weaknesses that have been designed into the product from its inception. These weaknesses may severely effect the producibility of the ship and further reduce the productivity that is witnessed in the shipyard.

Some of the responsibility for the existing situation lies with the shipbuilders. As has been discussed previously U.S. shipyards have had as much opportunity as their foreign counterparts to manage, develop, and market commercial ship designs. However, for various reasons, the industry has not openly embraced this market sector and currently finds itself lagging the world market in this regard. It may be worthwhile to explore why the domestic shipbuilding industry has not made a solid commitment towards diversifying its market base with commercial products.

The third area of the ship acquisition process that requires immediate attention is that of material identification and procurement. The application of

various types of standards could have broad implications when applied to this problem. Standard design modules, whose inherent characteristics would allow them to be used in various ship types, would allow for immediate material identification. These pre-designed interim products would not only shorten the design process but could also shorten the time required to obtain material. The concept of standards can also be applied to the sources of supply. A vendor should be qualified on the basis of product quality, on-time delivery, and cost. Once qualified, a vendor should be used as often as possible. This strategy, over time, will breed strong long-term relationships between suppliers and shipyards. Finally, the portions of the ship that must be custom designed and fabricated should be manufactured from standard shapes and sizes of raw materials. All of these areas require an immediate increase in research and development, and front-end planning and engineering.

There is no guarantee that implementing changes to these areas will result in new work. These changes will require the expenditure of risk capital on the part of the shipbuilding infrastructure. So what incentives are there for the industry to change? Where is the risk capital going to come from to pay for these changes? Should these funds be supplied from within the infrastructure or from outside sources? Could changes in government policy encourage and stimulate these types of expenditures? Could consortiums be formed within the industry to address any of these concerns? Are joint ventures with overseas companies the answer? These are questions that need to be answered by the shipbuilding infrastructure as a whole.

One way to help answer some of these questions is to find out how the competition currently accomplishes these activities. However, the development of a shipbuilding strategy for the future cannot be based solely on copying the competition. Information uncovered about the competition must be used to rationalize a strategy whose objective is to outperform the competition. Then, and only then, will the U.S. industry be capable of gaining a foothold in the global market. ISIS intends to support this rationale by analyzing how the competition is performing the ship acquisition process, and developing a future infrastructure option that will define the parameters for a competitive shipbuilding industry in the United States. These steps will follow closely upon the work already accomplished by ISIS.

Lessons learned during the development of the "As-Is" model will be used to further refine this IDEF₀ model. Constructive criticisms will continue to be incorporated into the existing model. Areas of the model where more detail is required will be further decomposed. This revised version of the "As-Is" model will serve as the foundation for all subsequent work.

The following step of the ISIS project will focus on analyzing competitive domestic industries and foreign shipbuilding industries that are at the leading edge of the

global market. The current plan calls for the establishment of direct contact with at least two maritime research organizations within the European Community and Japan. The purpose for establishing these research ties will be to facilitate the direct comparison of the competitions' approach to the ship acquisition process with established U.S. practice. The focus during this step will be on the time-drivers identified from the "As-Is" model. It will be determined if similar situations have been encountered by other domestic and foreign industries. Opportunities for improvement uncovered in the initial investigation will be specifically addressed by the input received from participants in this stage. The primary goal of this stage will be to develop a comparative basis by which the initial findings can be assessed.

The final stage of the ISIS study will develop a future ship acquisition process, referred to as the "To-Be" model. The "To-Be" model will demonstrate how the United States could be globally competitive on the basis of overall process duration. This model, or "future vision", will merely be an option that can be used as a target by the research and development communities within government, industry, and academia. Upon completion of this project stage, the industry would assume ownership of the model and use it to develop individual corporate business strategies and research and development initiatives. Both the "As-Is" and "To-Be" models would need to be housed and maintained by the industry so that they could be kept current in the ever-changing economic, political, and legal climate.

As the United States enters the 1990s, an issue of national proportions has emerged. The United States, as a maritime nation, is clearly at risk of losing its ability to build commercial ships competitively. The United States must either find the means to facilitate a rebirth of its shipbuilding industry, or, within the next decade, face the consequences of being completely dependent upon foreign sources for its marine transportation assets. It is clear that other seagoing nations have decided to take strong measures to ensure their shipbuilding competitiveness well into the 21st century. The United States should do nothing short of the same.

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Ship Conversion Project Monitoring - From the Customer's Viewpoint

VA-2

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ABSTRACT

Over the past ten years, the Maritime Administration (MARAD) has awarded and administered contracts for the major conversion of 15 vessels. Each of these projects involved vessel reactivation as well as conversion, and each contract was awarded on a fixed price basis.

The combination of fixed pricing and vessel conversion/reactivation creates a challenge to shipyards bidding for the contract in that price competition is intense while, at the same time, an unknown level of growth work can be expected in the vessel reactivation portion of the project. Moreover, the project being bid, inclusive of anticipated growth work, must be integrated into the overall orderbook within the shipyard. The need for careful planning by the shipyard from the beginning of bid preparation through the end of the performance period is clearly evident.

This SNAME paper, however, addresses not shipyard planning but continuing project monitoring and progress evaluation by the shipyard's customer. Such monitoring includes ongoing comparisons between the shipyard's planned and actual performance with respect to resource application and schedule adherence. From a technical standpoint; it involves compliance with contract and specification requirements. And finally, from a financial standpoint, it includes project progressing to provide the basis for periodic payments to the shipyard for completed work.

INTRODUCTION

The shipyard's plan for completing a major conversion/reactivation project on time and within budget involves integration of the project into other orderbook work, timely accomplishment of necessary engineering, timely procurement and receipt of material,

allocation of facilities and financial resources, and time-phased allocation of labor resources.

The customer's plan for monitoring a major conversion/reactivation project, on the other hand, must be essentially complete before the project is even bid because the solicitation must include all of the project monitoring considerations which the shipyard will be required to comply with. Fundamental among these considerations is the requirement for submission of specified information by the shipyard to the customer prior to contract award and throughout the contract period. This paper focuses on these information requirements without which effective contract monitoring and progress evaluation cannot be accomplished, even though inspection of in-process work may be satisfactory.

Successful completion of a major conversion/reactivation project in accordance with contractual provisions is a team effort. It is important that both the shipyard's plan and the customer's plan be accommodated within this effort.

PRECONTRACT CONSIDERATIONS

Pro Forma Contract Provisions

MARAD includes a pro forma contract in its bid solicitation which includes several basic requirements to assist in project monitoring and progress evaluation. Among these requirements are:

Inspection. The shipyard is required to provide specified facilities, materials and services necessary for the safe and convenient on-site administration of the contract. A MARAD Construction Representative is assigned the responsibility and authority to conduct ship and work site inspection and to accept shipyard work. All workmanship and materials, and all shipyard operational practices, are

required to be in accordance with the requirements of specified regulatory and other rule-making bodies. The vessel must be fully certified by the U.S. Coast Guard and the American Bureau of Shipping prior to MARAD acceptance for redelivery. In the event that vessel performance during specified dock and sea trials is unacceptable, the equipment in question is required to be opened for post-trial inspection and any defects for which the shipyard is responsible shall be corrected.

Information. At the beginning of the project performance period, the shipyard is required to submit a summary cost estimate and certain other cost data which are needed to establish an acceptable system of progress payments to the shipyard. This system of progress payments is addressed in greater detail later in the paper.

During the project performance period, the shipyard is required to provide all plans, schedules, documents and other information as specified in the plan and correspondence procedure which is also addressed in greater detail later in the paper.

Growth Work. There are two types of growth work in a MARAD contract for vessel major conversion/reactivation. The first applies to changes in contract requirements which may include changes in specified conversion work to be accomplished. The second applies to delivery orders for supplementary repair work. Whether for a change order or a delivery order, contractual procedures provide for full MARAD involvement in the technical identification and authorization of growth work. The process requires the shipyard to submit an estimate including labor hours, material quantities and cost, and an estimate of delay, if any.

The contract provision applicable to changes also addresses constructive changes and acceleration. The shipyard is required to provide written notice to MARAD if it believes MARAD has ordered such events.

Progress Reviews. The shipyard is required to conduct quarterly progress reviews for MARAD at the shipyard during which the categories of engineering, production, material procurement, logistics and outstanding contractual matters are addressed.

Monthly meetings between MARAD and the shipyard are also held at the shipyard during the in-between months to review physical progress of vessel conversion/reactivation.

Specifications. The contract specifications provided to the shipyard by MARAD address the technical aspects of the conversion/reactivation project. These specifications include additional requirements for additional information to be furnished by the shipyard which are addressed in greater detail later in the paper.

Basis of Contract Award. Of primary importance in the pro forma contract, from a project monitoring standpoint, is the provision which states that the contract will be awarded to that responsive and responsible bidder with the lowest total responsive bid and whose redelivery date does not exceed the contract redelivery date. The term "responsible" is key in that it mandates a determination of contractor responsibility by MARAD's contracting officer in accordance with the Federal Acquisition Regulation (FAR). FAR 9.104-1, General Standards, includes several specific requirements which a prospective contractor must meet to satisfy a favorable determination of responsibility. A pre-award survey is generally conducted by MARAD in order to assess whether these requirements are or can be met. The shipyard's plan for accomplishing the conversion/activation project is reviewed during the survey.

PRE-AWARD SURVEY

After bids are opened, MARAD contacts the apparent low bidder and then follows up with a letter confirming arrangements for the onsite pre-award survey and requesting the information included in Table I.

Latest audited financial statements and management letter from Certified Public Accountant firm

Completed MARAD information form (SF 17): Facilities Available for the Construction or Repair of Ships

Time-phased production workforce allocation plan (separate plans for conversion and reactivation/repair)

Preliminary key event schedule

Summary cost estimate and detail cost backup sheets

Vendor quotations for material, equipment and services exceeding \$10,000

Input for following pre-award survey forms:

SF 1403 (General)

SF 1404 (Technical)
 Resumes of key personnel
 Evaluation of technical capabilities
 Description of technical capabilities which yard lacks

SF 1405 (Production)
 Shipyard organization
 Production control system
 Plant facilities
 Production equipment
 Long lead procurements for project
 Major subcontracting
 Personnel
 Delivery performance record
 Related previous production (government)
 Current production orderbook

SF 1406 (Quality Assurance)
 Organization
 Instructions/procedures

SF 1407 (Financial Capability)

SF 1408 (Accounting System)

Table I Precontract Information
 from Apparent Low Bidder

The latest audited financial statements and management letter are needed to determine whether the bidder has or can obtain adequate financial resources to perform the contract.

The completed standard form SF-17 is needed to determine whether the bidder has or can obtain necessary production, construction, and technical equipment and facilities.

The time-phased production workforce allocation plan is needed to determine whether the bidder has, or can obtain, the necessary labor to perform the contract on a timely basis. Figure 1 is a typical workforce allocation plan which presents manhour loading by month and cumulative percent loading during the period when the vessel is in the yard. The fairly rapid buildup of manhours indicates that reactivation work commences at an early stage when engineering and material procurement for conversion work do not absorb a significant workforce. In Figure 1, the contract redelivery date is at the end of month 14.

The primary importance of Figure 1 from a project monitoring and progress evaluation standpoint is that it presents the shipyard's time-phased plan for allocating labor. Shipyard performance during the contract period is measured against this plan.

The preliminary key event schedule is needed to determine how the shipyard intends to approach the conversion/reactivation project. Will reactivation work be accomplished at the beginning, throughout or at the

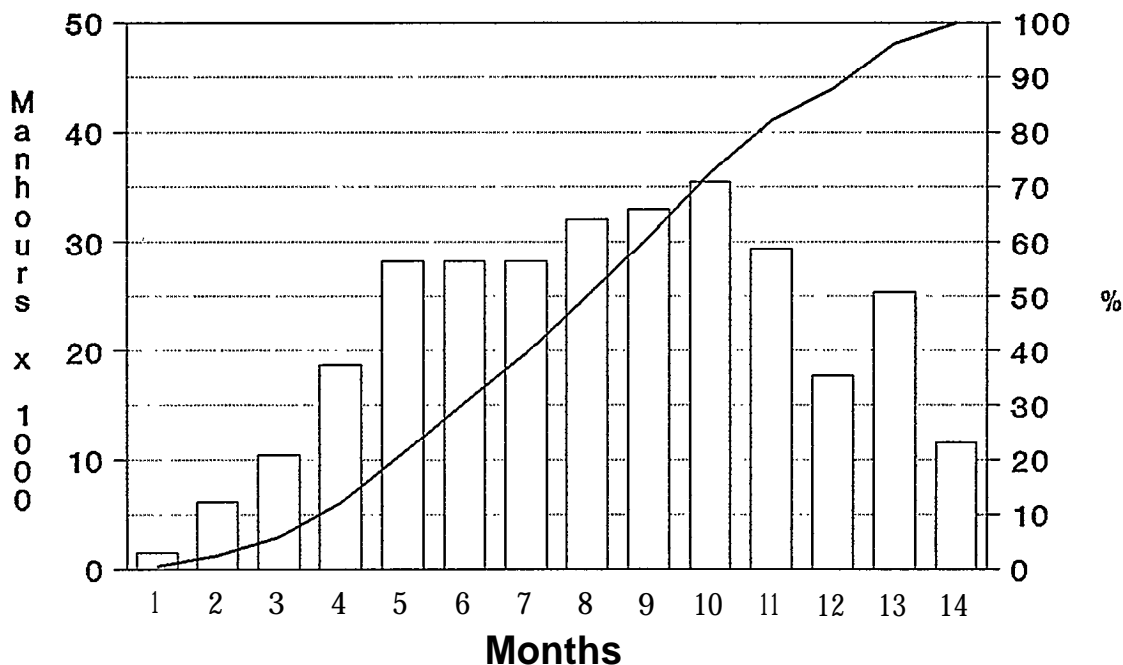


Figure 1 Time-Phased Production Workforce Allocation Plan
 for Base Contract Work

end? How long is conversion engineering expected to take? What are the target dates for receiving major equipments? Has the shipyard left anything off the schedule which MARAD considers important? Has enough time been allotted toward the end of the contract period for testing and trials? Answers to these types of questions provide MARAD with the secondary benefit of information pertinent to timely assignment of inspectors to its field construction office at the shipyard.

The summary cost estimate., detail cost backup sheets, and major vendor quotations are specific pro forma contract requirements. Although the shipyard is not obligated to furnish them prior to contract award, they do facilitate an effective pre-award survey and determination of responsibility.

The pre-award survey team must provide a complete survey inclusive of recommendations, to the contracting officer. This report is in the five sections indicated in Table I by the "standard form" (SF) identifiers. MARAD forwards blank forms to the shipyard prior to the survey and requests that appropriate information on the forms be completed to the maximum extent possible, and that the partially complete forms be returned to MARAD for review prior to the pre-award survey.

Thus far, this paper has addressed precontract considerations which impact on project monitoring. They provide a framework of requirements which the shipyard must comply with and a basic shipyard plan on how the work will be accomplished. The next section of the paper addresses post contract considerations which address information requirements provided for in the pro forma contract and contract specifications but which apply to the shipyard during the contract period.

POST CONTRACT CONSIDERATIONS

Table II is a list of information requirements in eleven specific areas

which, in aggregate, provide ongoing project monitoring information as work is being accomplished. All of these requirements are addressed in the plan and correspondence procedure which is an integral part of the pro forma contract.

Production schedules:

Key event schedule

Master production schedule
(Including material ordering schedule and test schedule)

Tank open and inspect schedule

Working plan schedule and plans

Purchase specifications

Equipment technical manuals and engineer's operating manual

Force reports

Progress photographs

Construction progress and payment report

Receipts for contractor-furnished and government-furnished material

Logistic support plan and schedule (including existing ship's inventory and condition report)

Test memoranda

Equipment and system technical reports as required by contract specifications

Table II Post Contract Information from Shipyard

Plan and Correspondence Procedure (P&CP)

Under the plan and correspondence procedure, the shipyard is required to provide a master production schedule and key event schedule (Figure 2) to MARAD within 45 days after contract award, and to update and reissue these schedules on a monthly basis.

Item No.	Item Description	<u>Planned</u>		<u>Revised</u>		<u>Actual</u>	
		<u>Start</u>	<u>Finish</u>	<u>Start</u>	<u>Finish</u>	<u>Start</u>	<u>Finish</u>
	Key Events			20-30	Items		
	Conversion			50-100	Items		
	Reactivation/Repair			50-100	Items		

Figure 2 Key Event and Master Production Schedules

The master production schedule is required to identify all engineering and production activities which impact on project scheduling. It generally includes 100 to 200 line items and is in sufficient detail so that critical path(s) to project completion can be identified. The format for both the master production schedule and key events schedule includes baseline (originally planned), revised estimate (schedule slippage in excess of 15 days), and actual start and finish dates. The data in these two schedules provide the primary basis for ongoing monitoring of production schedule progress and for review of production activity and problems at the quarterly and monthly progress meetings.

Because most of the vessels in MARAD major conversion/reactivation projects are in excess of 20 years old, the condition of their tanks is often suspect. Accordingly, a separate "open and inspect" schedule for all deep tanks, double bottom tanks, peak tanks; cofferdams, cargo tanks and any other tanks subject to regulatory body inspection is required to be submitted within 45 days after contract award. The schedule must be developed to ensure that all tanks are opened and inspected in sufficient time for all repairs to be identified, priced and submitted to MARAD for action within eight months after ship availability.

A working plan schedule is required to be originally issued within 60 days after contract award and reissued thereafter with updates on a monthly basis. MARAD approves all shipyard working plans. Those that are approved at the headquarters level must be turned around with 20 days; those at the field construction office level within 8 days. This ongoing plan approval process affords a good opportunity to monitor engineering progress and its impact on production.

Purchase specifications are required to be included in a material control schedule and are subject to the same MARAD approval process as shipyard plans. This ongoing purchase specification approval process affords a good opportunity to monitor material procurement progress and its impact on production.

New equipment technical manuals, reworked portions of existing equipment technical manuals and updated portions of the engineer's operating manual are all subject to approval by MARAD.

Figure 3 is a typical force report required by the plan and correspondence procedure to be submitted on a monthly basis.

In this report, the shipyard is required to include shipyard hours expended during the month just ended for both base contract work and growth work. The cumulative hours expended since contract award and expected hours at project completion for both of these categories must also be included. The total number of shipyard employees is included to provide a means to approximate the percentage of shipyard labor resources being expended on the conversion/reactivation project. For project monitoring and progress evaluation purposes, the monthly force reports provide actual labor expenditure data for measurement against planned labor expenditure data.

To assist in project monitoring, a minimum of five photographs are required to be submitted on a monthly basis. The five photographs include two to indicate overall views of the entire weather decks and superstructure and at least three, as selected by the shipyard, to indicate significant progress or status for specific items during the reporting month.

<u>Manhours Expended</u>		<u>Current Month Cumulative</u>	
Base Contract Work		26,253	171,239
Change Orders/Delivery Orders		<u>4,791</u>	<u>35,688</u>
Totals		31,044	206,927
<u>Estimated Manhours at Completion</u>			
Base Contract Work			306,000
Change Orders/Delivery Orders			<u>50,000</u>
Total			356,000
<u>Total Number of Employees</u>			724

Figure 3 Force Report (End of Month 10)

Under MARAD contracts for major conversion/reactivation projects, progress payments are made to the shipyard in accordance with physical progress achieved based on a 10,000 point system representing material and labor value components for specified work. Figure 4 is a typical contract progress certification system in which aggregate material accounts for 40 percent (4,000 points) of the contract value for base contract work and labor accounts for 60 percent (6,000 points).

The system typically includes up to approximately 20 line items in the general category for cost accounts such regulatory bodies, towing, performance bond, tests, trials, general services, engineering, etc. From 50 to 100 lines items are usually included in conversion cost accounts and from 150-200 line items are usually included in reactivation/repair cost accounts. The up-to-ten line items in major material procurements/subcontracts cost accounts occur when material suppliers or subcontractors require progress payments. These are "material" costs to the shipyard and MARAD does not pay progress for material until it is received at the shipyard unless special arrangements are made on a line item basis. These special arrangements permit progress payments for offsite work.

In Figure 4, the aggregate material completion percentage is 70.0 and the aggregate labor completion percentage is 45.2 yielding a base contract work completion percentage of 55.12 for the project. Subtraction of

the previous time period completion percentage provides an incremental progress increase which when multiplied by the base contract price yields the progress payment value for the current partial payment period. For project monitoring and progress evaluation purposes, the labor progress date is particularly important throughout the project for measuring against manhour expenditures, and toward the end of the project when monitoring efforts focus on work yet to be accomplished.

Progressing of growth work is separately handled on a line item basis. A change order or delivery order must be settled as to price before any MARAD payment for it is made. For a change order/delivery order settled for more than \$50,000, a MARAD payment can be made based-on the percent of work complete. Figure 5 is a typical change order/delivery order status report maintained by MARAD's onsite construction representative to, in part, assist in progressing growth work.

In Figure 5, the price for the lifeboats line item is settled so partial progressing can occur before the work is complete. Progressing at 100 percent for the radar line item can also occur because the work was completed on 11-3-89. For project monitoring purposes, the data in Figure 5 are particularly useful for keeping track of growth work line items in the administrative process from identification to approval. For major conversion/reactivation projects, the number of growth work line items

Item No.	Item Description	<u>Material</u>			<u>Labor</u>			<u>Total</u>	
		Point Value	% Comp.	Value Comp.	Point Value	% Comp.	Value Comp.	Point Value	Value Comp.
	General				20		Items		
	Conversion				50-100		Items		
	Reactivation/Repair				150-200		Items		
	Major Material Procurements/ subcontracts				10		Items		
Contract Totals		4,000	70.0	2,800	6,000	45.2	2,712	10,000	5,512
					<u>Agreed Price</u>	<u>% Comp.</u>	<u>Payable Amount</u>		
	Change Orders/Delivery Orders (\$50,000 or Less)				\$ 34,500	100	\$34,500		
	Change Orders/Delivery Orders (Exceeding \$50,000)				\$134,000	40	\$53,600		

Figure 4 Contract Progress Certification system

CO/DO No	Title	Estimated cost	CR Submittal Date	CO/DO Approval Date	yard Item No .	Price Settlement Date	Settled Price	Work Completion Date
001	Lifeboats	\$57,250	2-1-89	2-17-89	416	3-14-89	\$53,198	
347	Main Circ. Pump	4,729	8-23-89	9-2-89				
491	Radar	8,118	9-22-89	9-23-89	506	9-23-89	7,793	11-3-89

Figure 5 change Orders/Delivery orders status Report

typically exceeds 700.

To assist MARAD's construction representative in progressing the material portion of line items in Figure 4 and in generally monitoring the receipt of material for production support purposes, the shipyard is required to provide MARAD with warehouse receipts for both contractor-furnished and government-furnished material.

Contract specifications for major conversion/reactivation projects require a significant shipyard effort in the area of logistics. Specific efforts include existing vessel inventory, spare parts procurement, loose item outfitting procurement, packaging/ labeling, onboard stowage, equipment validation, equipment technical manuals, etc. The shipyard is required to provide a logistic support schedule in the same format as Figure 2 (key event and master production schedules). For project monitoring purposes, the data in the logistic support schedule are particularly useful in assessing progress toward logistics completion at vessel redelivery.

Test schedules and test memoranda are required to be provided by the shipyard. MARAD approval of test memoranda is coordinated at the field construction office level. Since testing and trials essentially constitute the final segment of project inspection, the thorough and timely preparation of test memoranda is an important element of project monitoring.

The final item under the plan and correspondence procedure being addressed in this paper is the requirement for the shipyard to provide variety of equipment and system technical reports addressed in contract specifications. These reports include equipment condition reports, tank

sounding reports, bearing clearance reports, cathodic protection reports, motor and generator megger reports, lube oil quality reports, etc. All of these reports assist MARAD's construction representative monitoring the project from the standpoint of inspection and need for specific growth work.

INSPECTION AND EVALUATION

Onsite Inspection

MARAD contracts for vessel major conversion/reactivation invoke FAR clauses 52.246-4 and 52.246-6 which, in turn, are based on FAR subpart 46.202-2, Standard Inspection Requirements, under FAR subpart 46.2, Contract quality Requirements. Subpart 46.202-2 states that the invoked clauses:

- "(1) Require the contractor to provide and maintain an inspection system that is acceptable to the Government;
- (2) Give the Government the right to make inspections and tests while work is in process; and,
- (3) Require the contractor to keep complete, and make available to the Government, records of its inspection work." (1)

Element (2) above and MARAD's contract progress certification system provide the cornerstones for MARAD's onsite inspection program regarding work in process. These cornerstones are supplemented by specific contract provisions and contract specification requirements. To assure compliance with contract/specification requirements, a MARAD field construction office is established at the shipyard and headed by a MARAD

construction representative. This construction representative has specified contract responsibilities and authorities and is supported by an inspection staff. The inspection staff includes an office manager and combinations of inspectors to perform hull, machinery, electrical and logistics inspection duties.

MARAD's construction representative and inspection staff constitute MARAD's primary means of project monitoring for work in process.

Progress Evaluation

Whereas onsite inspection applies to work in process, progress evaluation applies to overall contractual performance which is essentially accomplished at MARAD's headquarters level.

Figure 6 is a set of curves applicable to the time-phased expenditure of production labor for base contract work. The data points in the curves are consistent with data presented in Figures 1, 3 and 4. The vessel availability curve is simply a straight line projection of the vessel's availability for accomplishment of base contract work from arrival at the shipyard through

the contract redelivery date. The planned production labor expenditure curve is taken directly from Figure 1 which was provided by the shipyard to MARAD in connection with the pre-award survey. A variation of these data would be splitting the curve into two curves; one for vessel conversion and one for vessel reactivation. The actual production labor expenditure curve is taken from Figure 3, the series of which provide manhour expenditure data on a monthly basis. Bid labor hours for base contract work is the 100 percent data point for manhours. Although generally not necessary for normal progress evaluation purposes, the percent actual production labor expenditure monthly data points may be adjusted to reflect the estimated manhours at completion for base contract work in Figure 3 rather than bid manhours. For example, if the shipyard decides to "buy" a substantial amount of work it intended in its bid to accomplish with shipyard labor or if a serious overrun of labor hours is emerging, the 100 percent data point for manhours could significantly change and a recalculation of previous data point values may be needed for effective progress evaluation. The labor progress curve is taken from Figure 4, the series of which provide the required labor data.

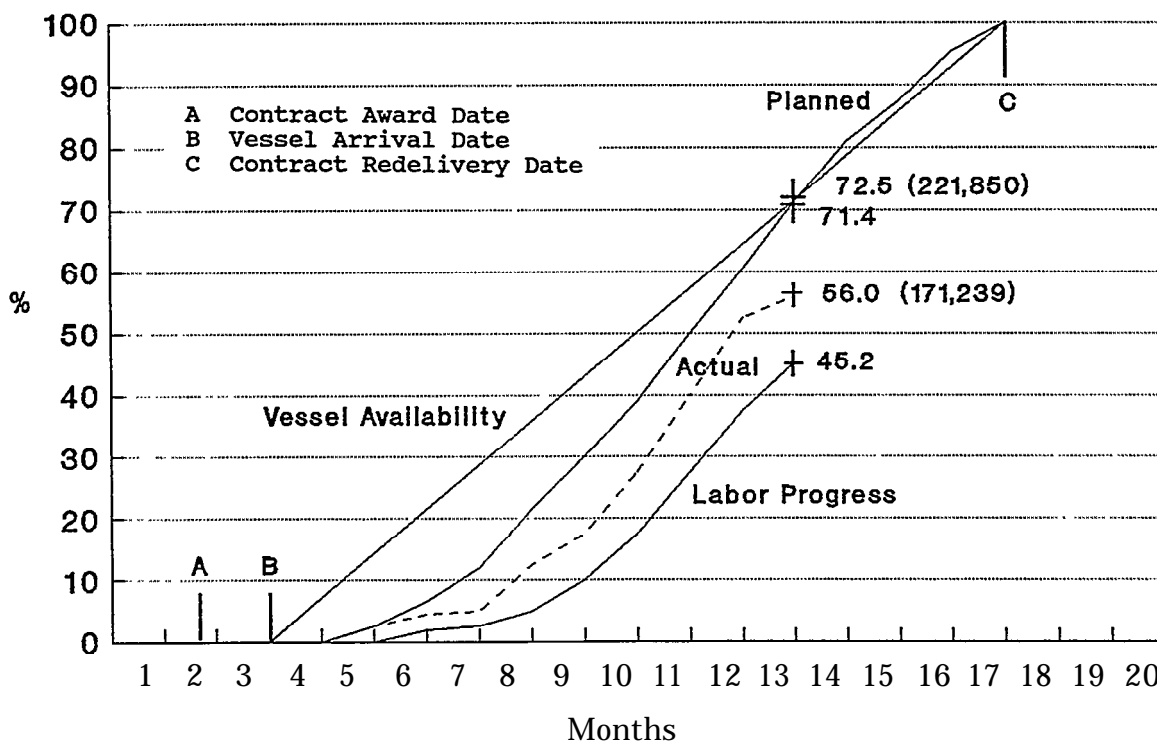


Figure 6 Time-Phased Production Labor Expenditures for Base Contract Work

The data in Figure 6 indicate that, as of month ten (13 minus 3), the following percentages apply:

Item	%	Manhours
Planned labor expenditure	72.5	221,850
Vessel availability	71.4	--
Actual labor expenditure	56.0	171,239
Labor progress	45.2	--

It is not possible to reach absolute conclusions from simplistic comparisons among the above data. It is possible, however, to identify trends and to suggest that specific possibilities should be examined in more detail. For example, actual labor expenditures lagged planned labor expenditures as of the end of month ten by 16.5 percent and divergence is evident. IS the project being undermanned? Has significant shipyard work been diverted to subcontract work? Should project manning be increased at this time? As another example, labor progress lagged actual labor expenditures as of the end of month ten by 10.8 percent. Is the shipyard

underprogressing from a labor standpoint? Is labor productivity less than it should be? Are hours being charged to this project that should not be? The worst case being suggested by the Figure 6 data is one of labor undermanning coupled with less than acceptable labor productivity. This may not be true but questions should be asked by both shipyard management and its customer, and answers should be found.

Figure 7 is the Figure 6 data extended to vessel redelivery with Case 1 reflecting a labor underrun and Case 2 a labor overrun. At this point in time, of course, we are no longer monitoring the project or evaluating progress but are assessing why the vessel was redelivered 80 days late and what happened to the manpower loading.

The data in Figure 7 indicate that, as of vessel actual redelivery, the following percentages applied:

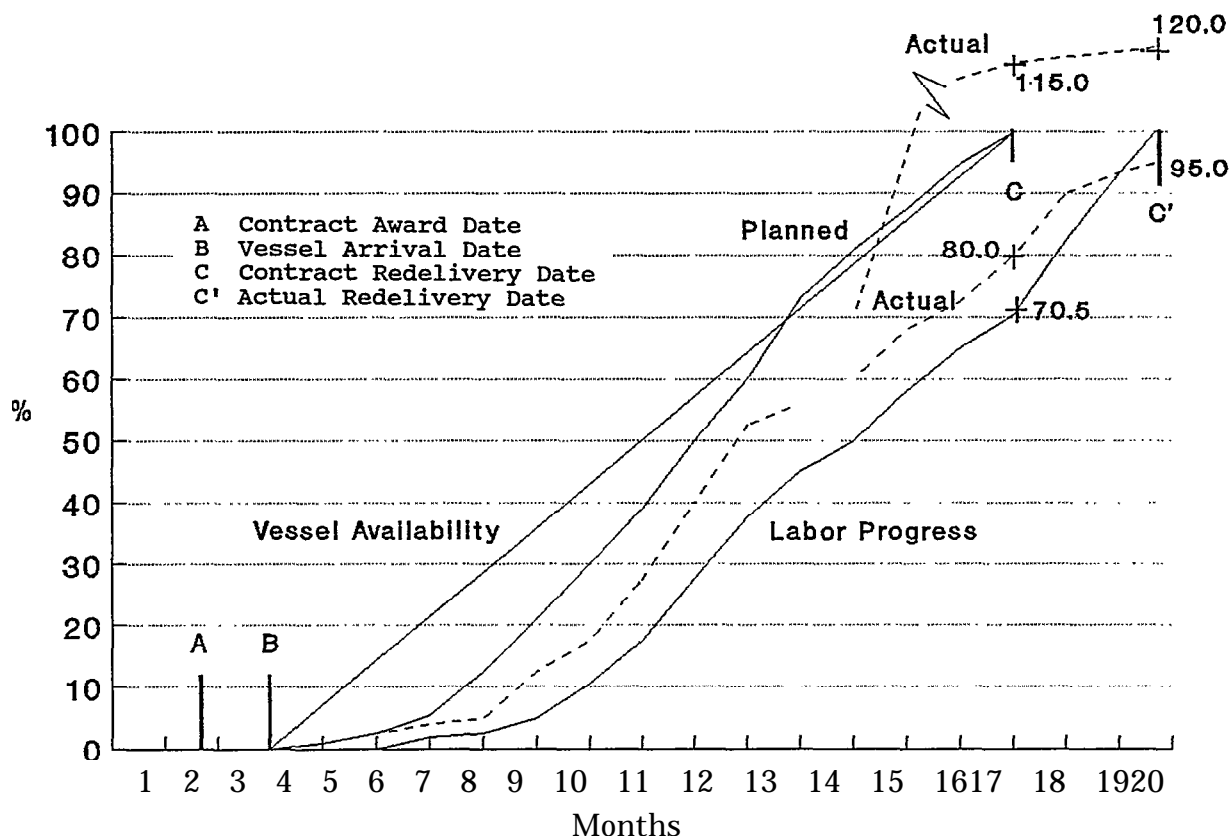


Figure 7 Time-Phased Production Labor Expenditures for Base Contract work - Delay

Item	Case 1 %	Case 2 %
Planned labor expenditure	100.0	100.0
Vessel availability	--	--
Actual labor expenditure (as of contract redelivery date)	80.0	115.0
Actual labor expenditure (as of actual redelivery date)	95.0	120.0
Labor progress	100.0	100.0

Again, it is not possible to reach absolute conclusions from the above data or from comparisons among these data. It is possible, however, to suggest that specific possibilities should be examined in more detail. For example, in Case 1, the actual expenditure of labor as of vessel actual redelivery was only slightly less than the planned expenditure; but the actual expenditure was only 80.0 percent as of the contract redelivery date. Was the project undermanned causing delay? Was the delay caused by growth work in lieu of base contract work? Was the delay the responsibility of the customer? Were portions of the contract specifications defective? In Case 2, the actual expenditure of labor as of vessel actual redelivery was significantly greater than the planned expenditure. In fact, the actual expenditure was already 15 percent higher than 100 percent of the planned expenditure as of the contract redelivery date. In addition to the above questions, was there poor labor productivity particularly toward the end of the project? Was there substantial disruption and inefficiency due to growth work? Is there a basis for shipyard submission of a request for equitable adjustment to the customer? Should shipyard labor data bases be updated for future bidding purposes?

SUMMARY

As stated in the Abstract, the combination of fixed pricing and vessel conversion/reactivation creates a challenge to shipyards bidding for the contract in that price competition is intense while, at the same time, an unknown level of growth work can be expected in the vessel reactivation portion of the project. This challenge also extends to the customer whose primary objective is project completion within budget, on time and in compliance with specification and approved growth work requirements. To achieve this objective, the customer should include sufficient provisions and requirements in the contract and

contract specifications to assure an opportunity to effectively monitor the project and to evaluate progress during the period of performance. This paper has presented actions taken by the Maritime Administration to help assure that its project monitoring and progress evaluation processes are effective.

REFERENCE

1. Federal Acquisition Regulation (FAR) subpart 46.2, Contract Quality Requirements



A Data Model for the Integration of the Pre-commissioning Life-cycle Stages of the Shipbuilding Product

VB-1

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ABSTRACT

This paper reports some aspects of the work being carried out on the NEUTRABAS project under the ESPRIT II European research program. The aim of this project is to specify and implement a neutral product definition database for large marine-related artefacts, covering a large part of the complete product life-cycle. The results of this research program will facilitate the effective exchange of product-related data between disparate computer-based information systems, and hence promote a movement towards product life-cycle integration. The scope of the product model being developed as the basis for this integration is described in terms of its spatial and steel structural components, together with the implications for integration with other models of outfitting and engineering systems. The model is shown to encompass the wide range of product-related data which is associated with the various pre-commissioning stages of the product life-cycle. A suitable database architecture designed to support product data exchange and full life-cycle integration based on this product model, is described and discussed.

NOMENCLATURE

AEC	Architecture, Engineering and Construction.
ASCII	American Standard Code for Information Interchange.
CAD	Computer Aided Design.
CADEX	CAD Geometry Data Exchange.
CAD*1	CAD Interfaces.
CALS	Computer Aided Acquisition and Logistics Support.
CEC	Commission of the European Communities.

EDI	Electronic Data Interchange.
ESPRIT	European Strategic Program for Research and Development in Information Technology.
IGES	Initial Graphical Exchange Specification.
ISO	International Standards Organisation.
NIDDESC	Navy Industry Digital Data Exchange Standards Committee.
SET	Standard d'Exchange et de Transfert.
VDAFS	Verband der Deutschen Automobilindustrie Plaechen Schnittstelle.

INTRODUCTION

The pre-commissioning stages in the life-cycle of large, complex engineering artefacts, of which the shipbuilding product is an example, are normally associated with the generation and management of vast quantities of complex, inter-related product data. This data is concerned with all aspects of the product including its geometry, topology, functionality, the associated production processes, production planning and control, materials, quality control and so on.

The scope and complexity of the product-related data being created and manipulated throughout the various pre-commissioning stages of the complete product life-cycle, from requirements analysis, through the various design stages and finally into production, requires that equally comprehensive and coherent data models be specified and implemented to enable the effective management and exchange of such diverse product data between the associated application areas. The need for such data models is accentuated by the tendency to use increasingly complex heterogeneous computer-based information systems at the various pre-commissioning life-cycle stages. These life-cycle stages cover activities such as marketing, conceptual design,

detailed design, drafting, materials ordering, production planning and control, scheduling, and quality control. The use of such diverse software and hardware systems presents considerable obstacles to the effective management and control of the massive amounts of data related to the product which these systems both generate and use.

In theory, a product data model could and should be extended to cover the full life-cycle of the product, from the initial feasibility studies/requirements analysis, through the design and production stages, its operation, maintenance, possible upgrading and finally its decommissioning and eventual demolition. This would ensure that all information concerning the product would be available in a consistent and system-independent form throughout the full product life-cycle and even beyond. This period may typically span more than 20 years; much longer than several computer system hardware and software architecture life-times. It is appreciated, however, that the definition and implementation of a complete product data model covering all of these aspects of the life-cycle of an engineering product as complex as a ship is an onerous task, and one which would require the commitment of a vast amount of time and effort.

This paper reports on work currently in progress in Europe on the development of a data model which will facilitate the integration of those life-cycle stages of the shipbuilding product up to its commissioning and final hand-over.

STANDARDS FOR LIFE-CYCLE INTEGRATION AND PRODUCT DATA EXCHANGE

The many, non-trivial problems associated with the management and exchange of product-related data, have resulted in the inauguration of a large number of separate, but largely complementary initiatives, looking at the information management requirements of a wide range of manufacturing industries. These initiatives have resulted in the specification of a number of standards in the area of electronic data interchange (EDI). In some cases these specifications have been implemented to provide functioning data exchange systems for a range of application areas.

Early attempts at the development of standards for data exchange were largely concerned with geometry-based information. One such standard, IGES (Initial Graphical Exchange Specification) (1), allowed for the storage and transfer of basic 2-dimensional geometry between different computer-aided design (CAD) systems in a system-independent form. Although supporting the integration of those activities which are based upon geometrical data, IGES does not offer any facilities for the representation of information

regarding the topology, functionality, material characteristics, production processes and management information associated with a product, and cannot therefore be used as a vehicle for the integration of information flow throughout the the complete product life-cycle.

Standard for the Exchange of Product Data

One of the most significant attempts to circumvent the limitations of standards such as IGES is currently being carried out by a committee of the ISO (International Standards Organisation) and is commonly known as the Standard for the Exchange of Product Data (STEP) (2). The aim of this initiative is to provide a complete representation of all of the information which can be associated with a product throughout its lifetime in a completely system-independent form. That is, the basic goal is to enable a product to be represented from the requirements definition and conceptual design stages through to production, maintenance and eventual demolition. This representation is intended to include all geometric and non-geometric data associated with that product. Information types to be represented include geometry, topology, functionality, cost, materials, strength and safety. STEP is formulated in a structure consisting of an application layer upon an implementation layer, with the former comprising the relevant, domain-specific data models, and the latter the actual implementation of these models. The EXPRESS data modelling language (3) has been specifically developed for use within the application layer.

A large number of individual data models reside within the STEP application layer, being classified as either application models or resource models. Application models, such as the shipbuilding and the AEC (Architecture, Engineering and Construction) models, address the requirements of particular application areas. Resource models, such as geometry or topology, are not generally associated with a specific application area, but provide general facilities to application models. Resource models currently nearing completion within the STEP standard include geometry, topology, solids, features, material, presentation, AEC core and tolerances. Similarly, application models nearing completion include drafting, ship structures, electrical applications and finite element analysis.

A STEP data model provides a description or specification of a domain of interest and consists of entities, attributes and relationships. Entities may be either abstract, such as a powering calculation, or concrete concepts such as a stiffener piece-part. Entities may be described by a number of attributes and referred to other entities via relationships. The data model contains descriptions and other information including the

constraints upon the value of attributes, global constraints and textual descriptions with some explanation of entities. All STEP data models are ultimately described in the EXPRESS data modelling language.

The actual transfer of data between individual applications is achieved by means of a physical file. The STEP standard allows for the use of ASCII characters only in the physical file description, and requires the format to be human readable. However, in the majority of cases it is not necessary for the developer of a model to be aware of the actual appearance of the physical file.

Other Initiatives

In addition to STEP, a number of adjunct EDI projects are currently under development, some of which are providing a significant contribution to the STEP activities. Many of these initiatives are collaborative ventures supported by the Commission of the European Communities (CEC) under the ESPRIT program of research and development.

ESPRIT (European Strategic Programme for Research and Development in Information Technology), founded in 1983 and currently at phase II, has included a number of projects which have been significant to the development of STEP such as CAD*I (CAD Interfaces) and CADEX (CAD Geometry Data Exchange). Many other initiatives, also related to STEP, have originated in the United States and Europe in support of a wide range of industrial interests. Examples of these are the CALS (Computer-aided Acquisition and Logistics Support), NIDDESC (Navy Industry Digital Data Exchange Standards Committee), SET (Standard d'Exchange et de Transfert) and VDAFS (Verband der Deutschen Automobilindustrie Flaechen Schnittstelle) initiatives. Further details of all of these initiatives can be found in (4).

The one common aim that all of the aforementioned initiatives share, is that of providing the means for the effective storage and exchange of product-related data between different applications in a completely system-independent form.

One other project which is making a significant contribution to the STEP initiative is the ESPRIT project NEUTRABAS (5), a project which is specifically addressing the needs of the shipbuilding industry, and one which is the subject of this particular paper.

NEUTRABAS - A NEUTRAL PRODUCT DEFINITION DATABASE FOR LARGE MULTI-FUNCTIONAL SYSTEMS

The shipbuilding industry in Europe has consistently been at the forefront of technological advancement, with massive investment in computerized systems in all parts of the technical and production areas. This application of state-of-the-art technology, as illustrated by the introduction of computerized design and drafting systems, management information systems, and advanced automated manufacturing technologies, has repeatedly highlighted the need for some means for consistently storing and transferring information in an electronic format, between the various activity areas.

This perceived need resulted in the development of a proposal for a collaborative project under the ESPRIT initiative, which would involve a team of industrialists, academics and computer scientists from four European countries. The three year NEUTRABAS project started in April 1989 and involves fifteen partners from the UK, France, Germany and Spain. The overall aims of the project can be summarised in terms of four main points, as indicated below :

1. The standardization of the way in which information concerning marine-related products is represented;
2. The development of standard methods for the exchange and storage of product definition data in the marine industry;
3. The specification and development of a suitable database architecture which will facilitate the exchange and storage of such product definition data; and
4. The implementation of a prototype data exchange and storage system, based on the previously defined database architecture, which will demonstrate the feasibility of a truly integrated product life-cycle.

The Anticipated Benefits of the NEUTRABAS Approach

The most obvious of the anticipated benefits to arise from the application of the NEUTRABAS philosophy is that of life-cycle stage integration. This will be achieved through the coherent and consistent storage and exchange of product-related information between different application systems. In addition to this, a number of related benefits can be perceived, as indicated below.

- **Reduced project time-scales** - The adoption of a single, carefully managed information store will enable overall project time-scales to be reduced. This will be achieved through the rigorous control of information flow and the subsequent avoidance of mis-matches in information requirement and availability at each of the pre-commissioning life-cycle stages.
- **More effective information management** - A single, shared information storage facility will enable the more effective management of all product-related data including security, version control and data consistency issues.
- **Rapid information dissemination** - The adoption of a common shared information resource will result in more rapid information dissemination among the various activities involved at each of the pre-commissioning life-cycle stages.
- **Avoidance of data transcription** - The exchange of information between different application systems in an electronic format will avoid the need for manual or mechanical transcription of the data, with the accompanying risk of error introduction.
- **Improved supplier/client interface** - In an industry such as shipbuilding, which has a high level of bought-in items in its finished product, considerable benefits will be obtained from the provision of component and equipment catalogues and specifications in an electronic format, which can be incorporated into the product definition database. This will ensure that the most up-to-date information is always available concerning items of equipment obtained from outside sources.

THE DEVELOPMENT OF A SHIPBUILDING PRODUCT INFORMATION MODEL

The main aim of the information modelling process is to develop a structured representation of the information associated with a real-world physical object, which extends over the required life-cycle stages, and also supports the required views or interpretations of the product at each of these specified stages.

According to STEP, the shipbuilding product is a specialisation of the general AEC (Architecture, Engineering and Construction) category of real-world physical products. The complete life-cycle of the shipbuilding product extends from the requirements definition/mission analysis stage, through the various design stages, into production and then on to operation, maintenance and eventual demolition. At each of these various life-

cycle stages, the actual physical object being considered will normally be unchanged in the global sense, although the information associated with the product and the techniques used to represent it will vary considerably. For example, at the very earliest of the design stages, the conceptual design stage, the product will usually be described in very general terms using high-level (global) information, such as intended speed, gross capacities, main dimensions etc. As the design stage progresses, additional information concerning the product will become available and so the early global product information will be supplemented by more detailed, lower-level information.

This evolution and maturing of the information associated with the product, as it progresses through its various life-cycle stages, demands that any model of this information must be specified and developed with these life-cycle stages in mind. In the context of the NEUTRABAS project it was not considered feasible to attempt to define an information model which would support all of the product life-cycle stages mentioned previously, as this would require resources and expertise not available within the existing NEUTRABAS program. Those product stages which are considered in the NEUTRABAS product information models are associated with the pre-commissioning part of the product's life-cycle.

It has already been mentioned that the information associated with the physical product matures as the life-cycle progresses. In addition to this maturing process, the same information is subject to different points of view or interpretations during a given life-cycle stage. For example, if a physical entity such as a deck is considered at the detailed design stage, the way in which this object is described will be dependent upon which particular design activity is being considered. The draftsman producing scantling drawings will be primarily concerned with loadings, material properties, stiffening arrangements, precise geometry and so on. Whereas the naval architect investigating flooding, stability and other safety-related characteristics of the product may consider the same entity as a simple planar element without any of the previously mentioned characteristics.

It can therefore be seen that different views or interpretations of the same product require different aggregations of the information associated with the product. The problems associated with developing a coherent model of the information are further compounded by the conflicting approaches used at the design and production stages of the product life-cycle. For example, design is basically a top-down modelling activity with global concepts being repeatedly decomposed into smaller information-bearing units at

subsequent stages in the design process, with the associated increase in the level of detail of information. In contrast, production-oriented information modelling follows a bottom-up strategy, with individual information units being aggregated to form larger units and eventually the complete product definition.

In view of the above points, it can be concluded that any information model of a complex physical product must not only possess the scope and structure to reflect the evolution of the associated information as the product life-cycle progresses, but must also be able to facilitate different views of the product information at each of these life-cycle stages. It is with these requirements in mind that the information models of NEUTRABAS have been developed to provide a complete and coherent representation of the shipbuilding product, throughout the relevant life-cycle stages, which accommodates both the decomposition and aggregation scenarios associated with the pre-commissioning stages of the complete product life-cycle.

Information Modelling Techniques

The NEUTRABAS product model is basically comprised of a large number of physical and abstract objects which are described by means of sets of attributes. The formal specification of this model is therefore mainly concerned with the complete and unambiguous description of these objects (entities) and attributes, together with the means by which they are interrelated to form the complete description of the product. To this end, the description of the entities and attributes and the declaration of the relationships between them is achieved in three ways. First of all, a natural language (English) description of the entities and attributes is given which explains the context in which they are used and the restrictions or rules which affect their usage. Secondly, the entities and attributes are represented in a graphical form. The technique used for this graphical representation is the Nijssen Information Analysis Method (NIAM) (6), as adopted by the ISO/STEP community. The NIAM diagrams illustrate the relationships between the various entities which comprise the model, and also specify the restrictions imposed on the relationships between the individual entities and attributes. The final method used to describe the components of the product model is the EXPRESS information modelling language. This language provides a means of generating a formal, standardized textual description of the components of the model, together with the relationships between the various entities and attributes involved.

When combined, the three methods described

above provide a complete and coherent description of the product information model of NEUTRABAS which forms the basis for the implementation and testing phases of the project described in subsequent sections of this paper.

THE NEUTRABAS PRODUCT MODEL

An analysis of the form and structure of the information associated with the shipbuilding product identifies four basic views of the information which combine to give a complete description of the product throughout its pre-commissioning life-cycle stages. These four views are listed below.

1. Marketing-oriented view;
2. Management-oriented view;
3. Design-oriented view; and
4. Production-oriented view.

Clearly, a shipbuilding product model must support each of these high-level views of the product-related information in order that integration of the associated activities and life-cycle stages can be supported.

When commencing the analysis of the information to be modelled, it is convenient to categorize the information in terms of whether it is associated with the hull of the vessel or with the machinery and outfitting systems. This enables the information analysis in these two complementary areas to be carried out in parallel, with agreed integration points providing the means for the concatenation of the two sub-models. In the context of NEUTRABAS, this approach was adopted in the product modelling process with the result that two information models were developed covering the information concerned with the hull of the vessel, and that associated with the machinery and outfitting systems. This paper is primarily concerned with the model which describes the information associated with the hull of the vessel and which covers both the steel structure and the spatial arrangement of the product.

The High-Level Product Model

In very general terms, information relating to the shipbuilding product can be placed into one of three main categories :

1. Global information;
2. Information relating to the hull; and
3. Information relating to machinery and outfitting systems.

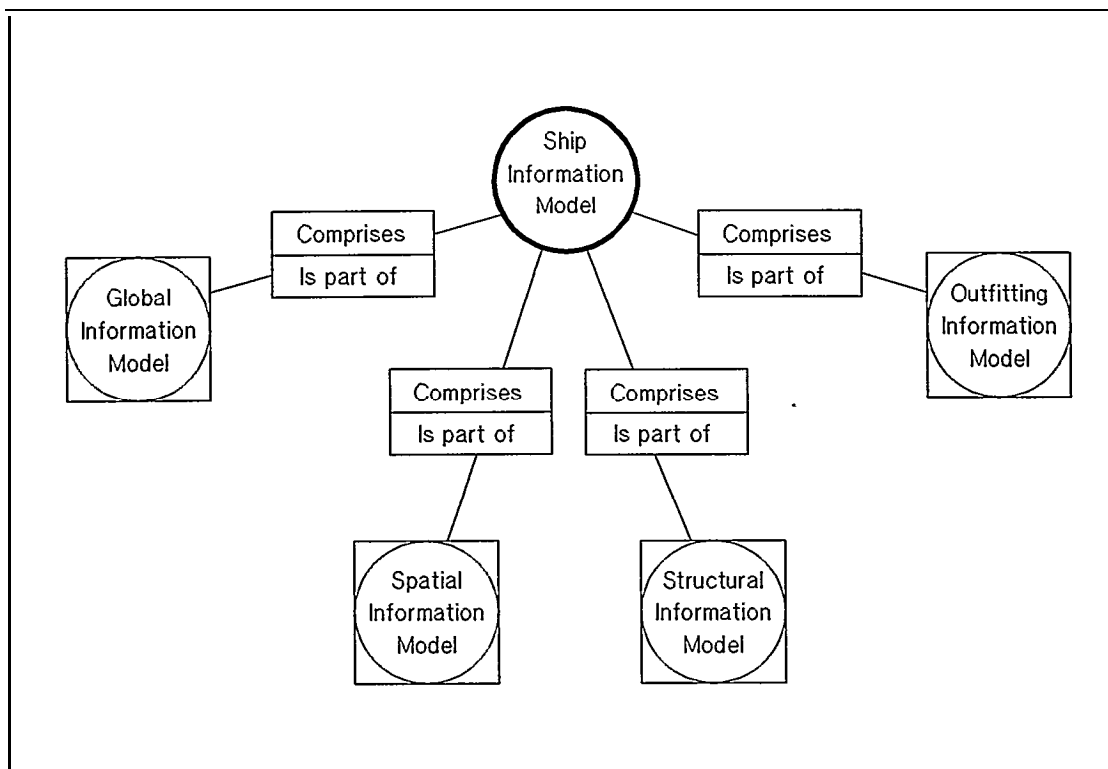


Fig.1 NIAM diagram of the NEUTRABAS high-level model.

Therefore, at the highest level, a shipbuilding product information model can be considered as comprising separate sub-models of global, hull and machinery/outfit information, as shown in NIAM form in Fig.1.

The Hull Model

As mentioned previously, a product model contains descriptions of a number of physical or abstract objects and their associated attributes together with details of their relationships with other objects. In the context of the NEUTRABAS hull model, the entities can be divided into two main categories; those associated with the representation of the structure of the vessel and those associated with its spatial organization. Although these two groupings can be considered as distinct concepts, in reality they are mutually dependent, a fact which is reflected in the NEUTRABAS hull model.

The spatial organization model. Reference to the spatial characteristics of the shipbuilding product will be found at all of the pre-commissioning life-cycle stages. In fact, the earliest of the design-related stages, the conceptual design stage, is almost entirely concerned with the spatial aspects of the product, i.e. the definition of an acceptable general arrangement for a design proposal. This will involve the manipulation of simple planar elements which com-

bine to form the boundaries of enclosed spaces or compartments, and the gross sub-division of the product into various functional zones, i.e. cargo spaces, machinery spaces, accommodation etc. It should be appreciated that the decisions made at this stage in the design process concerning the spatial organization of the product can have a significant effect on the overall quality of the finished product in terms of both its production and operational characteristics. Even at this early stage, the spatial organization of the product will be related to production, operational and other considerations. For example, the disposition of the main transverse sub-division members will normally be based on standard lengths of cargo holds, derived either from consideration of the size of cargo units to be carried (containers, pallets etc.), or from the maximum plate size which can be accommodated by the production facilities being considered (reduced work content etc.).

At each of the stages in the complete product design cycle, information relating to the spatial organization of the product will be required as this forms the basis for many of the associated design activities. In fact, many design activities rely solely on the availability of spatial-oriented information relating to the product. The nature of this information will change as the design process progresses from the concept stage to the detailed production-oriented design stage, reflecting the evolution and maturing of the product description.

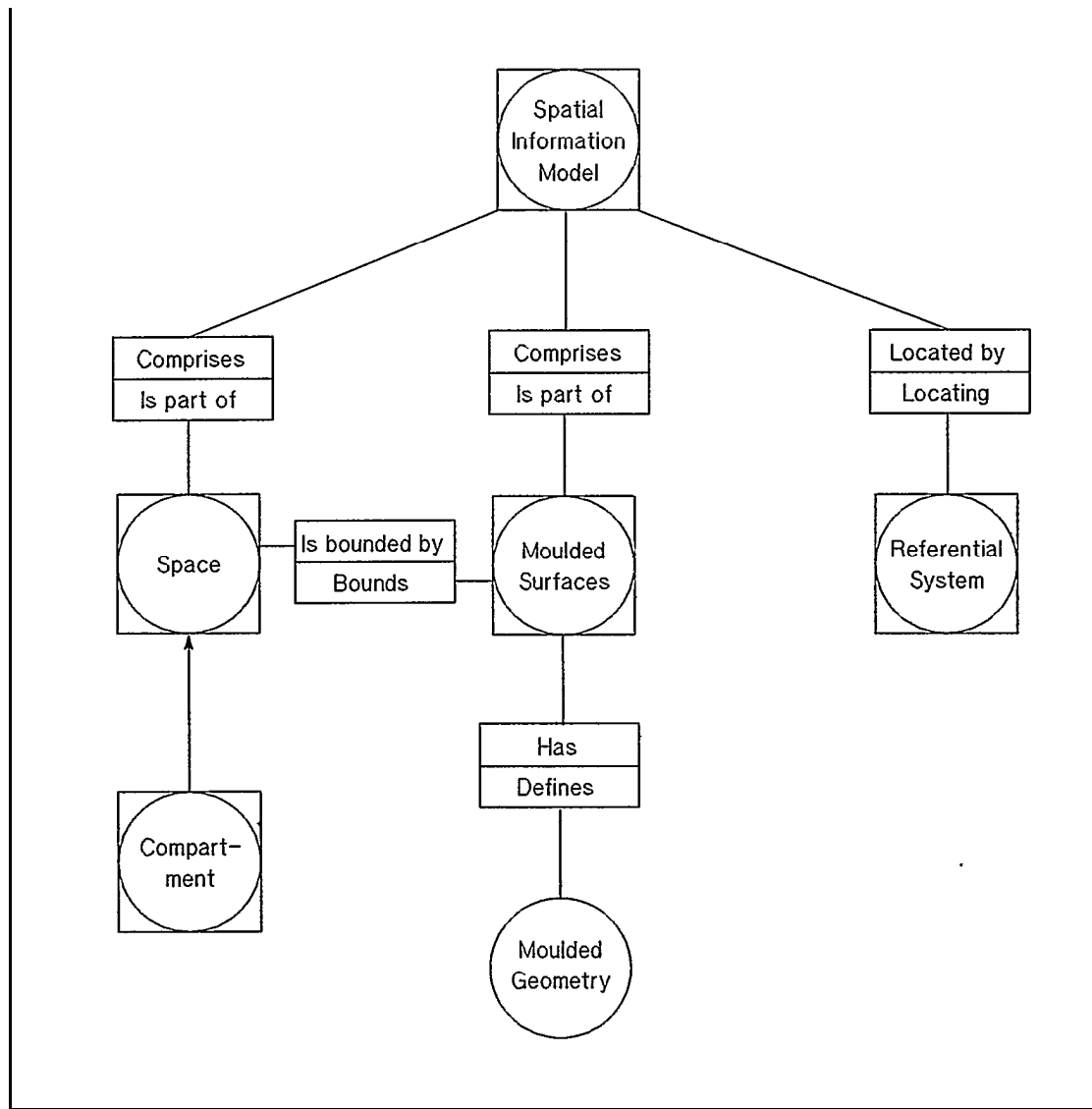


Fig.2 NIAM diagram of the spatial organisation model.

The need for the spatial organization model to reflect this evolution of the product definition through the various life-cycle stages and to support different views of the information, is therefore quite obvious.

In the context of NEUTRABAS, the spatial organization model is comprised of a number of basic elements which combine to support geometrical, topological and functional descriptions of the space-related characteristics of the complete product. These components of the NEUTRABAS spatial organization model are shown in NIAM form in Fig.2. The aim of this spatial model is to support the many applications which require space-oriented product information pertaining to the various pre-commissioning life-cycle stages.

It is to be appreciated that the spatial organization model, like all of the other NEUTRABAS information models, draws upon the information contained in the general resource models of STEP such as those concerned with geometry and topology. The integration of these general models with the spatial organization model removes the need for the explicit declaration of the associated entities within the model being described here.

As can be seen in Fig.2, the NEUTRABAS spatial organization model is basically a collection of systems which combine to describe the geometrical and topological characteristics of the internal organization of a vessel. These include the definition of the surfaces which combine to form the internal arrangement of the product, the internal enclosed spaces or compartments, and the reference systems which facilitate the orientation and location of components of the product in

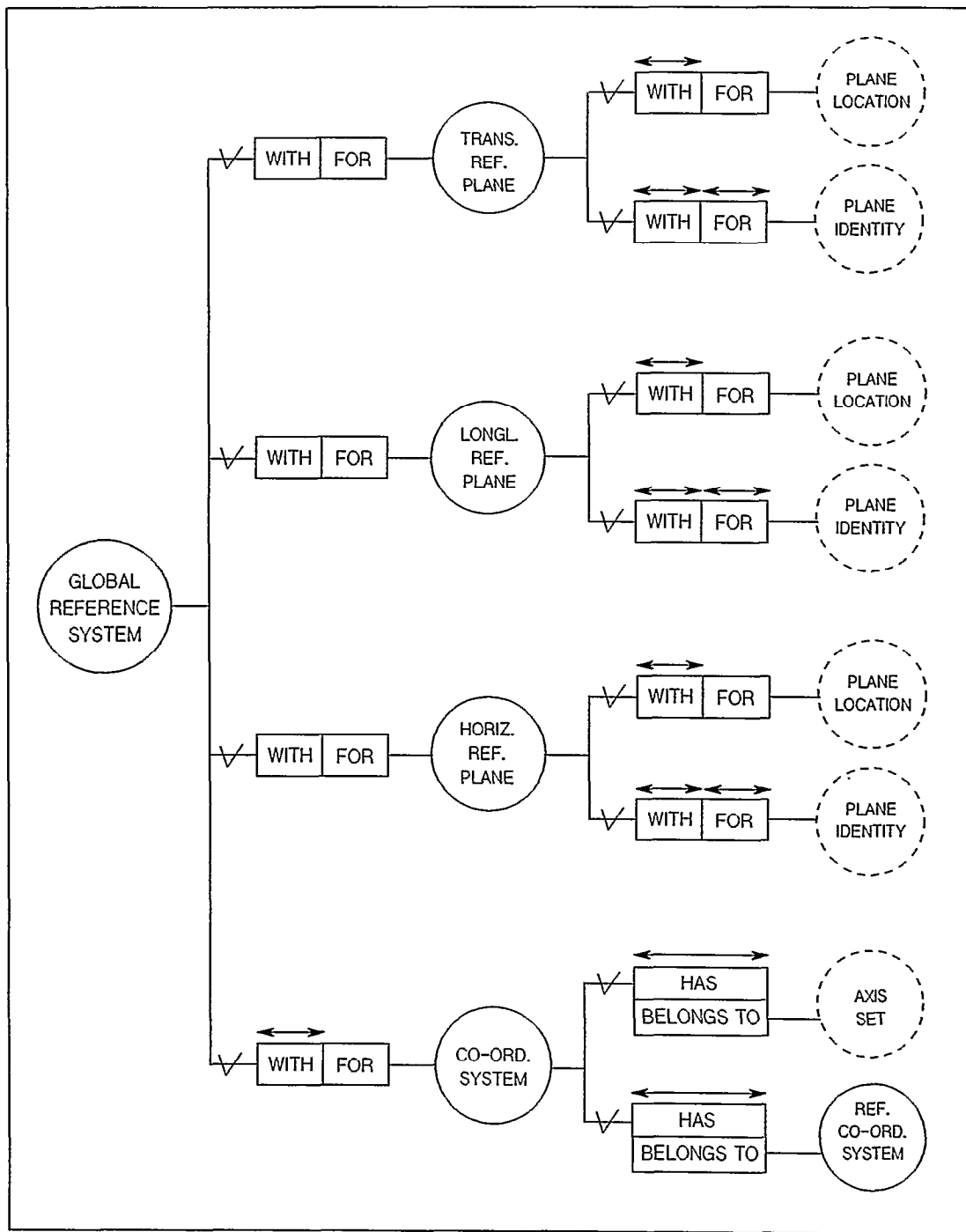


Fig.3 NIAM diagram of the global reference system concept.

three-dimensional space.

In order to illustrate the breadth and depth of the NEUTRABAS spatial organization model the following paragraphs describe a number of the components of the model in terms of the entities involved together with their associated attributes and their relationships with other entities.

The global reference system. The global reference system is perhaps one of the most important components of the spatial organization model as it provides the means for the orientation and location of all of the abstract and physical objects associated with the definition of the product. The NEUTRABAS global reference system concept is shown in NIAM form in Fig.3, and can be seen to comprise a number of elements as

listed below :

- one or more transverse reference planes;
- one or more longitudinal reference planes;
- one or more horizontal reference planes; and
- a co-ordinate system.

Transverse, longitudinal and horizontal reference planes can be associated with the location and orientation of physical entities such as frames, bulkheads, decks and so on, or abstract entities such as the boundaries of functional zones. The co-ordinate system component is itself comprised of two separate parts; a reference co-ordinate system and an axis **set**. This reference co-ordinate system has associated with it a global origin and its own axis set. The global reference system concept is shown diagrammatically in Fig.4.

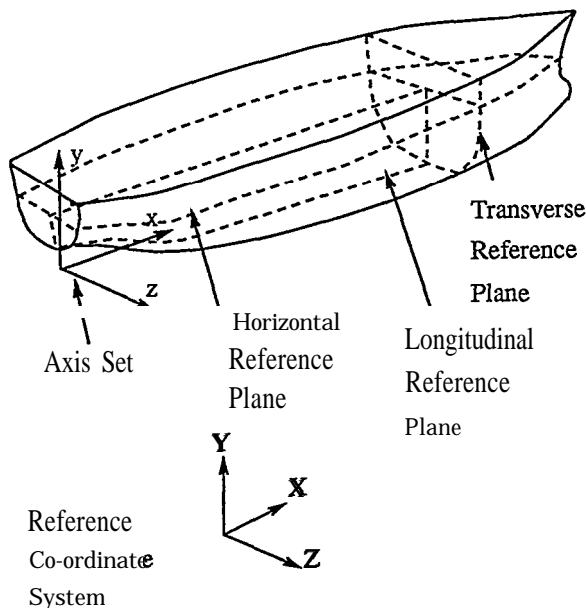


Fig.4 Diagrammatic representation of the global reference system concept.

Internal compartmentation. The spatial organization model, as its name suggests, is also concerned with the representation of the internal enclosed spaces on a vessel. This representation requires the introduction of the concepts of spaces, compartments and moulded surfaces. Moulded surfaces are non-structural boundaries within the overall envelope of the product, which may provide the topological and geometrical references for associated structural boundaries. Moulded surfaces may also form part of the boundaries of physical or hypothetical enclosed

spaces within the internal arrangement of the product. A variety of means can be used to define these surfaces including a variety of mathematical techniques such as the Bezier and B-spline formulations. The NIAM representation of the moulded surface concept is shown in Fig.5, which also indicates the various attributes which are associated with a particular occurrence of a moulded surface.

As mentioned above, moulded surfaces can define the boundaries of the internal enclosed spaces on a vessel. These spaces can either be hypothetical sub-divisions of the vessel, as in the case of a functional sub-division, or physical compartments used for the carriage of revenue-earning material or material required for the effective operation of the vessel such as fuel oil and water. The compartment concept is shown in NIAM form in Fig.6, and diagrammatically in Fig.7. Fig.6 shows the various types of compartments which can be found on a vessel, with the attributes which can be possessed by any compartment being shown in NIAM form in Fig.8, although it should be appreciated that particular types of compartments will have additional attributes which are peculiar to them.

As mentioned previously, the spatial organization model is closely related to that of the structural organization as it provides references for the location and orientation of the associated structural components. Additional details of the NEUTUBAS spatial organization model can be found in (7).

The structural organization model. The NEWTRABAS structural organization model is largely based upon a top-down analysis of the information associated with the representation of the structural components of the shipbuilding product. The structure of the model is based upon the repeated decomposition of the information-bearing units into their constituent parts until the required level of granularity or detail is achieved. This approach can be compared to the overall design process where high-level representations of the product are repeatedly refined until the complete product is defined in terms of individual piece-parts and components. This top-down view of the product may be representative of the design process, but is in direct opposition to the normal production-related view which tends to follow a bottom-up approach where individual piece-parts and components are aggregated to form sub-assemblies, assemblies, units, blocks and eventually the complete product. Therefore, in order to support the information requirements of the production-related life-cycle stages, the NEUTRABAS structural model has to support both the decomposition and aggregation views of the product.

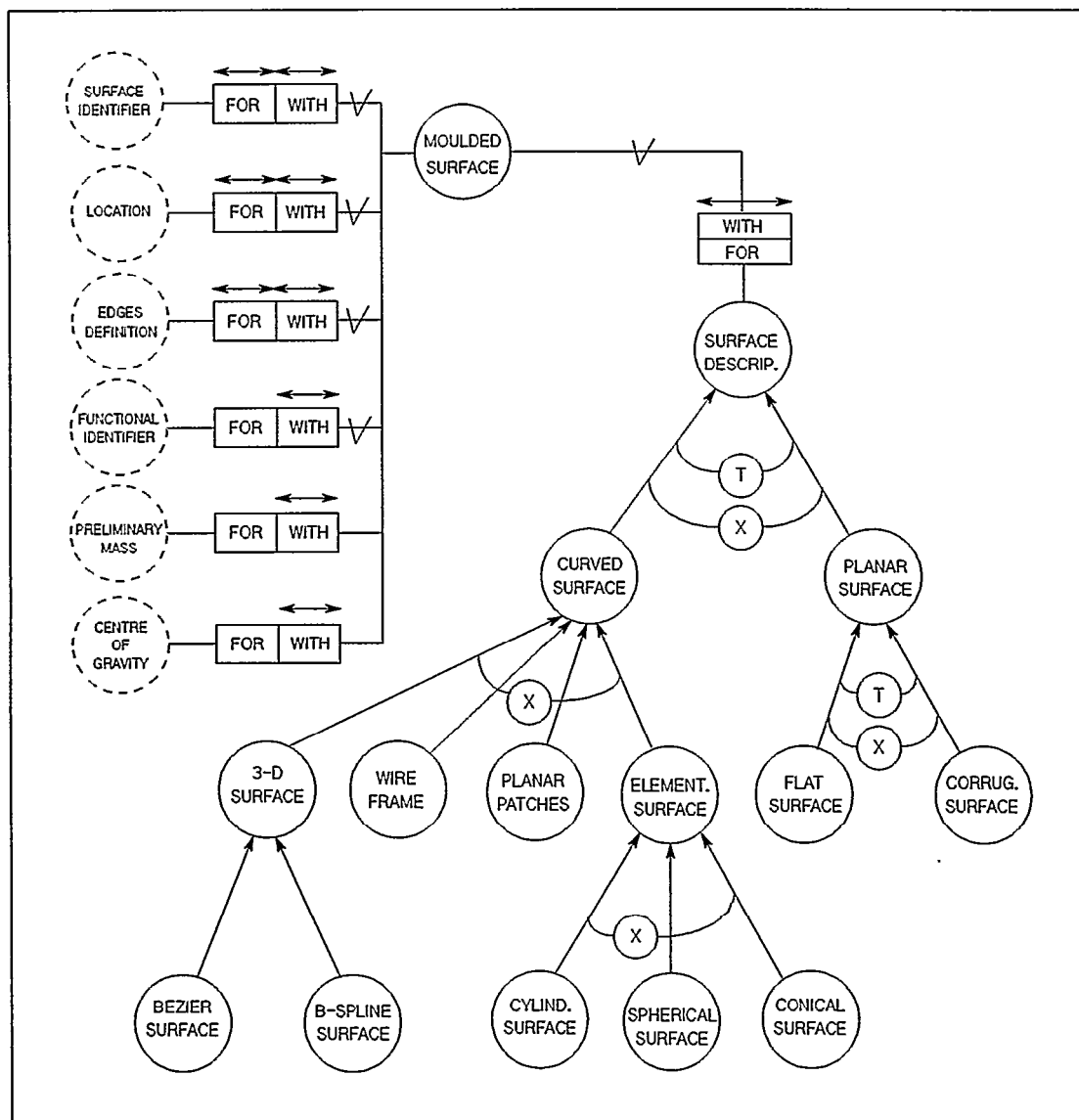


Fig.5 NIAM diagram of the moulded surface concept.

The generalised NEUTRABAS structural organization model is shown in NIAM form in Fig.9. The diagram shows that the structural system of the shipbuilding product is considered as comprising a number of non-overlapping structural elements, where each of these structural elements corresponds to a functional zone of the vessel, i.e. a double-bottom region or a main engine compartment. These individual structural elements are composed of a number of pre-fabricated blocks which are themselves made up of pre-fabricated sub-blocks or units which contain assemblies of plate and stiffener piece-parts. This decomposition is illustrated in NIAM form in Fig.10, and shown diagrammatically in Fig.11. It can be appreciated that this type of representation of the information associated with the structure of the vessel is predominantly a production-related view of that product as these pre-

fabricated blocks and sub-blocks are the primary outputs of the various production processes. However, the general model also incorporates a different view of the structural representation of the product, one which is associated with the various design stages. This design-related view considers the structural elements to be comprised of a collection of primary sub-structures which correspond to the major plate panels together with their associated stiffening members. These plate panels represent the major structural entities of the vessel such as complete decks, bulkheads and the outer shell. This type of representation is comparable with the view often used at the design stages where the structural arrangement of complete decks or bulkheads are considered without regard for the eventual sub-division of the entities which is required for the production processes, and is shown in NIAM form in Fig.12.

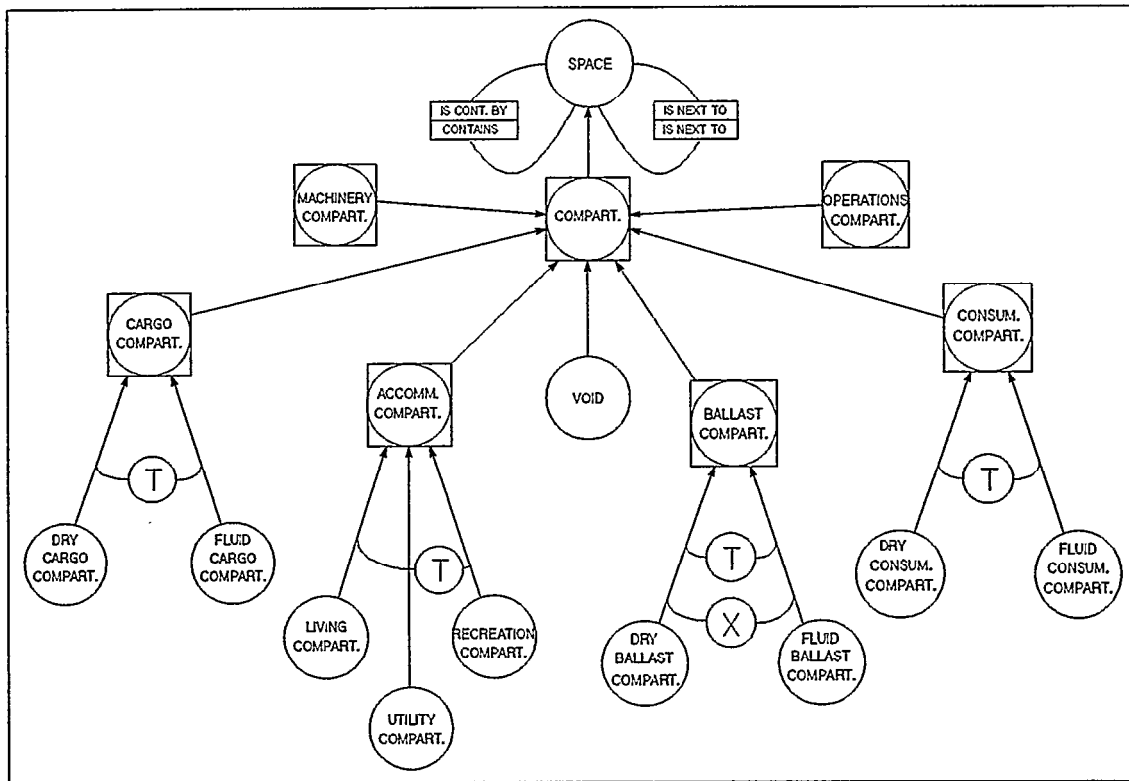


Fig.6 NIAM diagram of the compartment concept.

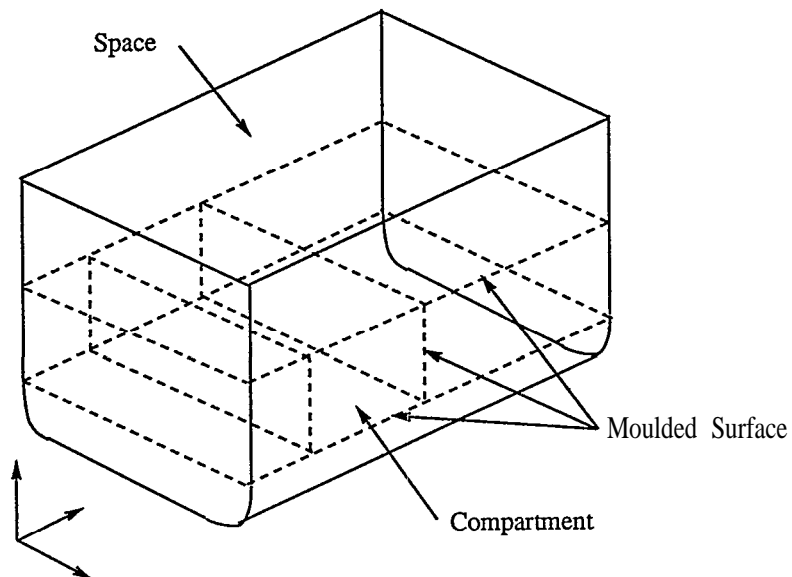


Fig.7 Diagrammatic representation of the compartment concept.

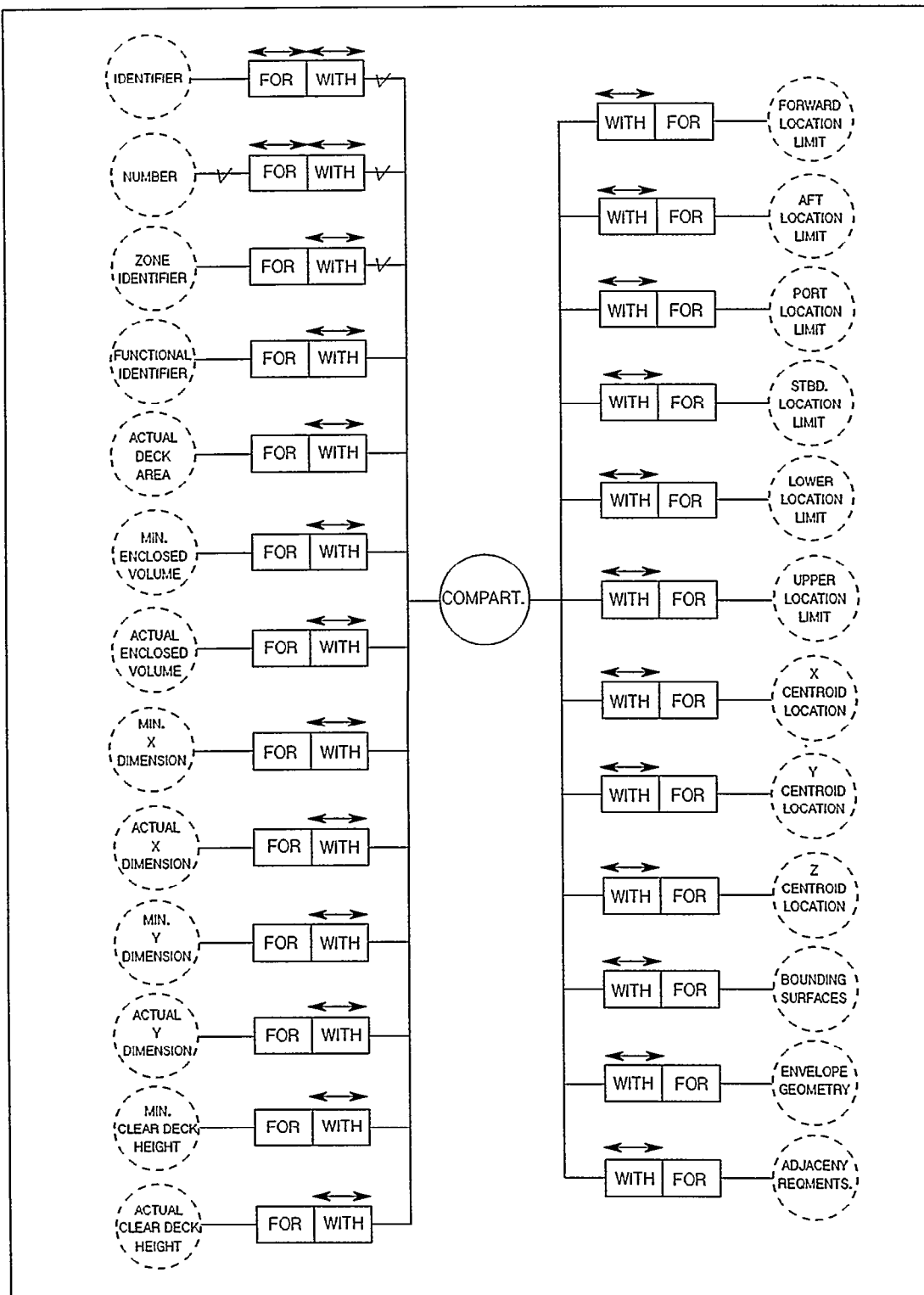


Fig.8 NIAM diagram of the compartment concept and attributes.

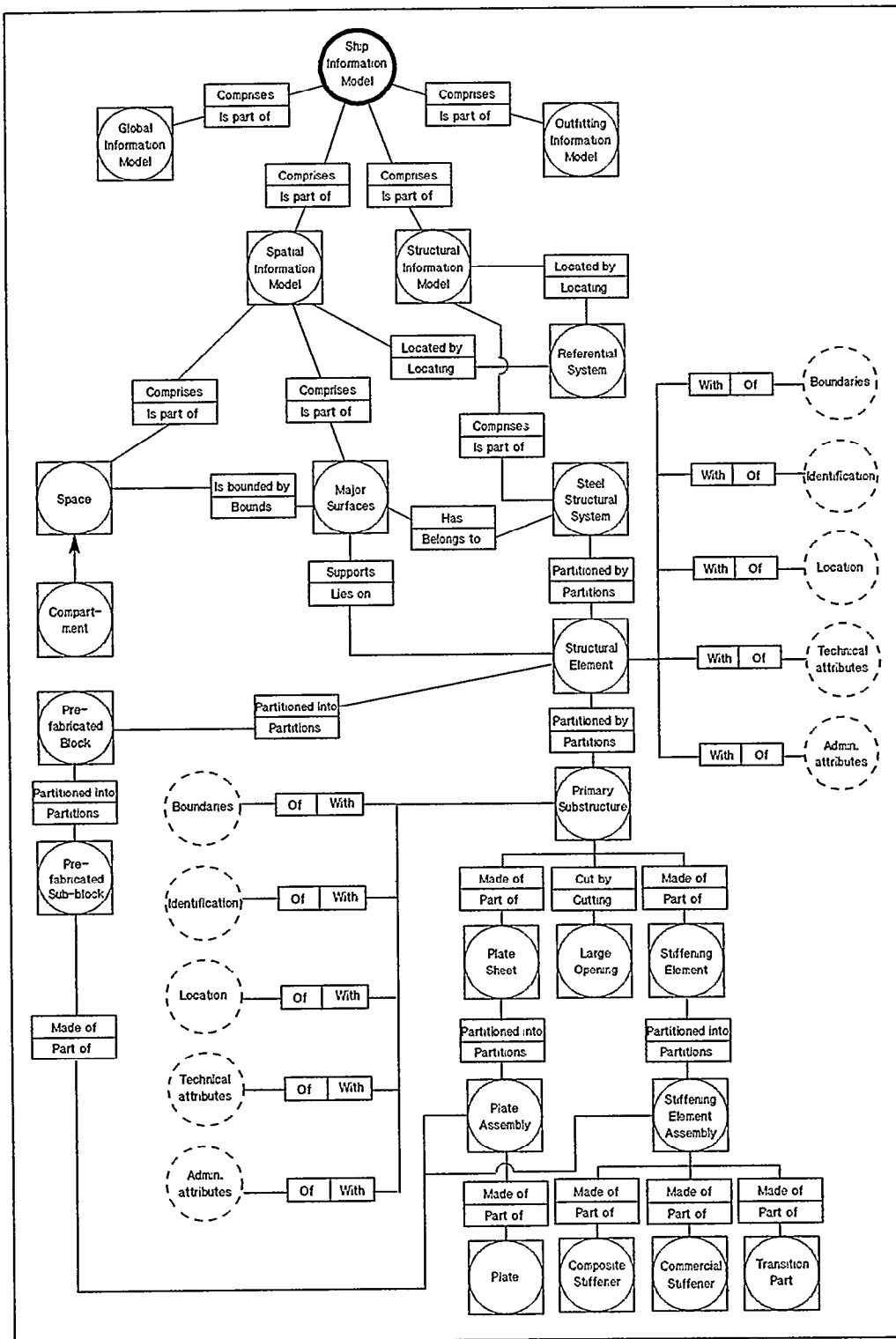


Fig.9 NIAM diagram of the general structural model.

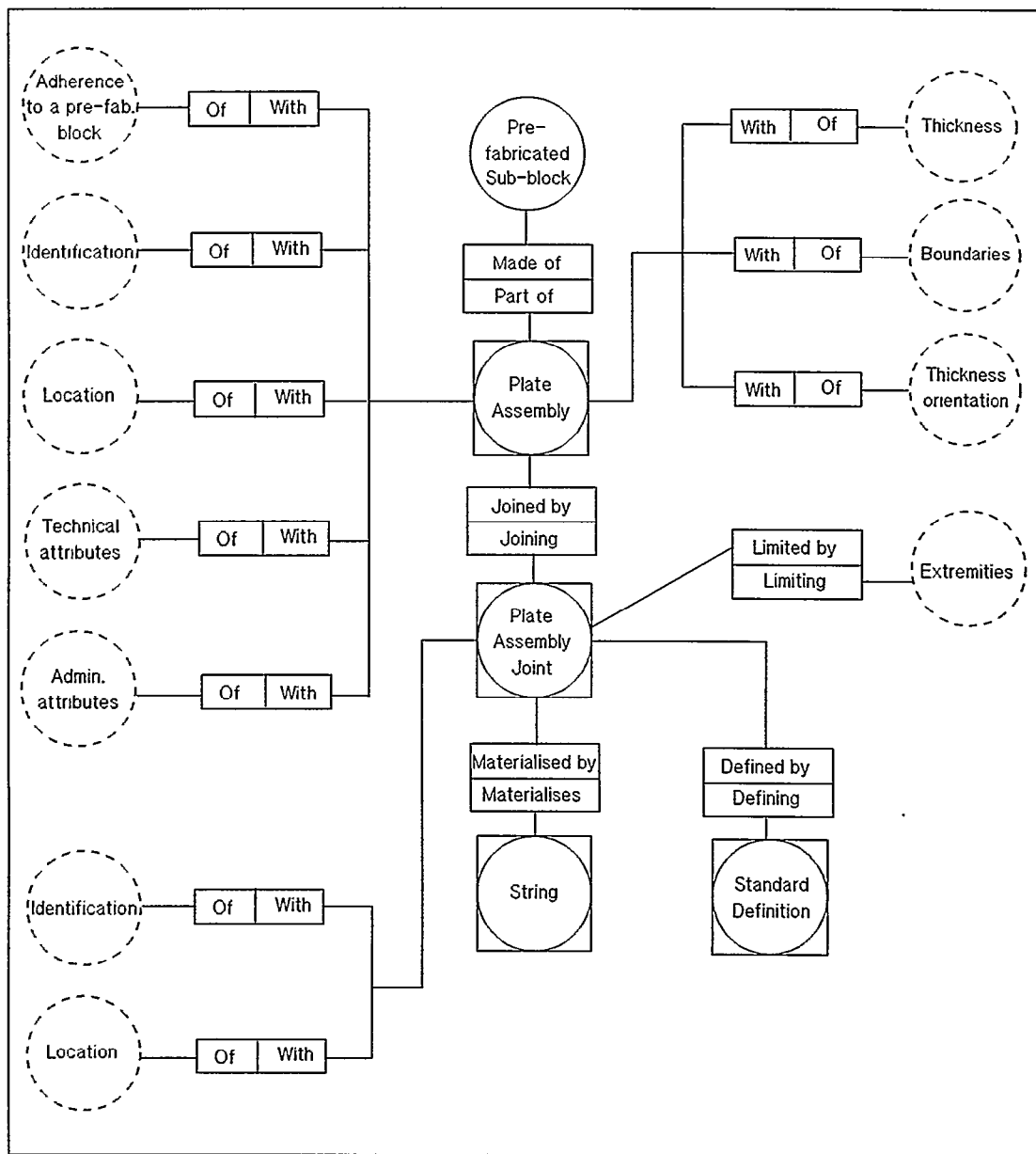


Fig.10 NIAM diagram of the sub-block concept.

The NEUTRABAS structural model has been developed so as to support both of the major views of the product which are associated with the pre-commissioning life-cycle stages, i.e. design and production. The complete model defines all of the information which can be associated with the structural system of the product including information such as the type and grade of materials, the weights and centres of parts and assemblies, details of welding procedures, and production management information, as well as information concerning the precise geometry and scantlings of individual parts and assemblies. Further details of the structural model can be found in (8).

Model Integration

The previous sections have briefly described a few of the components of the NEUTRABAS hull information model. The complete hull model provides a comprehensive definition of the type and structure of the information which can be associated with the hull part of the shipbuilding product. It should however be appreciated that the hull model is only one part of the complete description of the complete product, and that the various systems which are installed in the hull such as HVAC, electrical, pumping and the various machinery systems, are of equal importance in the specification of the complete shipbuilding

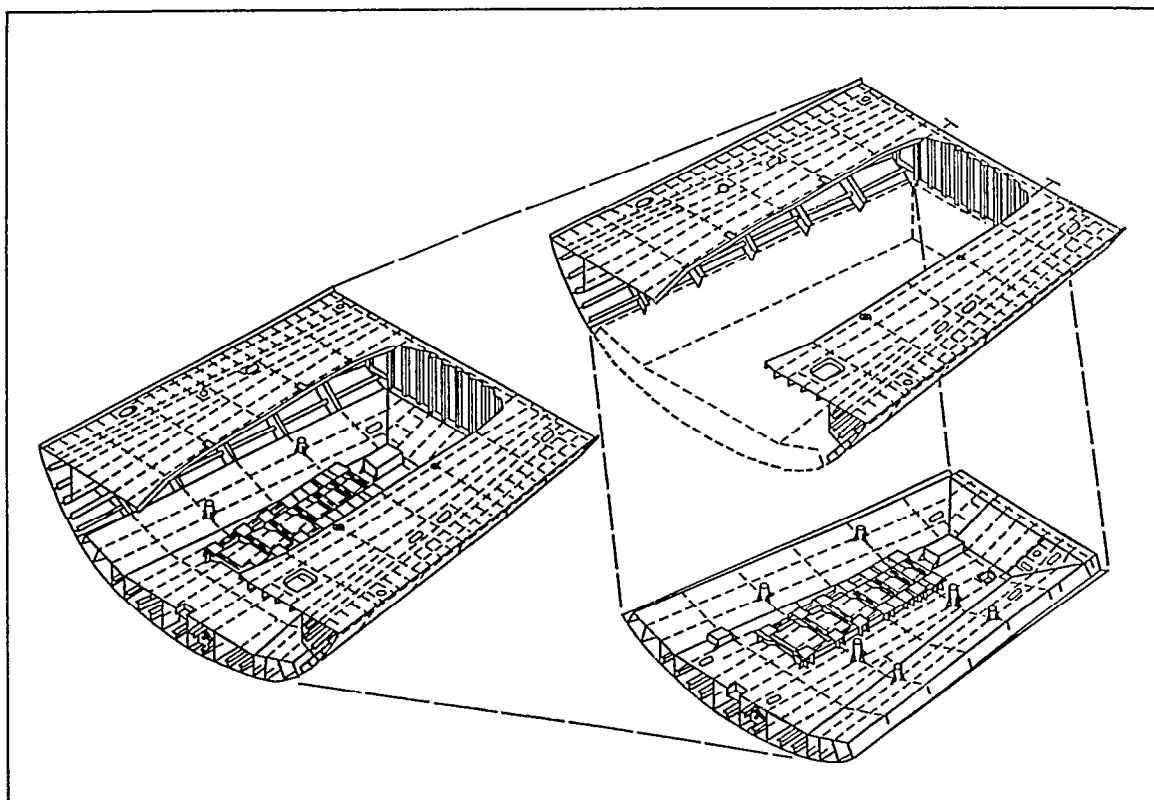


Fig.11 Diagrammatic representation of the sub-block concept.

product model. The machinery and outfitting systems model is fully described in (9). In addition, the various resource models defined by STEP have to be integrated so as to provide access to descriptions of entities dealing with topics such as geometry and topology.

The integration of these separate sub-models into a single product model is currently receiving considerable attention within the NEUTRABAS project, as it **is this fully** integrated model which will form the basis for the implementation of the product definition into a working data exchange and storage facility.

THE NEUTRABAS SYSTEM ARCHITECTURE

As previously stated, the NEUTRABAS project is different from many of the related activities in that it will be taken beyond the formal specification stage and will achieve partial implementation. In order to reach this implementation phase, a significant part of the effort associated with NEUTRABAS has been devoted to the specification and implementation of a suitable system architecture, as described in (10), which will facilitate the effective management and transfer of product data in the shipbuilding industry context. A brief description of the main

features of the NEUTRABAS system architecture is given in the following sections.

Requirements of the Proposed Architecture

When considering a suitable system architecture for the NEUTRABAS project, a number of significant requirements were identified, as indicated below.

- The system would have to be hardware and software independent as the typical shipbuilding product life-cycle is in excess of 20 years; a period far exceeding the current and anticipated life-spans of both computer hardware and software.
- The system would have to be capable of storing both information models and data models as the storage of data only in a neutral format is of no real value. The semantics of the relationships between the data items will also need to be defined and stored.
- The system would need to be independent of the application area. As NEUTRABAS is intended to cover all of the pre-commissioning stages of the product life-cycle, it has therefore to be capable of storing information together with the view or

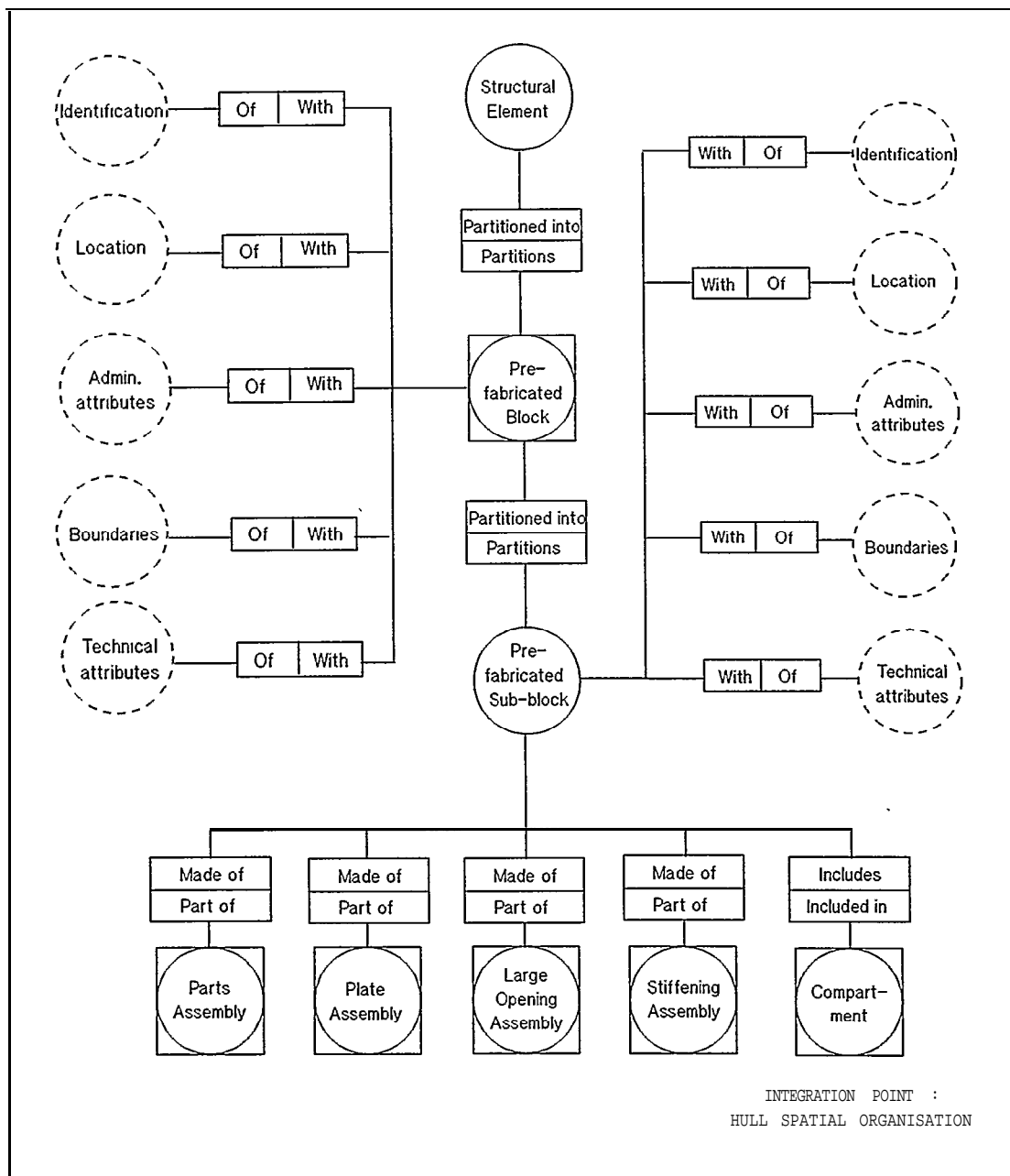


Fig.12 NIAM diagram of the structural element concept.

interpretation of that information for any application system at any stage in the product's pre-commissioning life-cycle.

- 1 The system would have to be dynamic as NEUTRABAS will be able to share information between large number of application systems and users, and must therefore have the capability to interrogate and update the database asynchronously. Equally, it must allow for the evolution of the information model itself.

The Proposed Architecture

The proposed main components of the complete NEUTRABAS implementation environment are shown diagrammatically in Fig.13. The NEUTRABAS system architecture is intended to provide all of the means necessary for the creation of schemata, from previously defined product information models, for a variety of database management system architectures; the facilities needed for the effective management of product data contained in these databases; and the various interfaces which will permit various application systems to communicate with this neutral

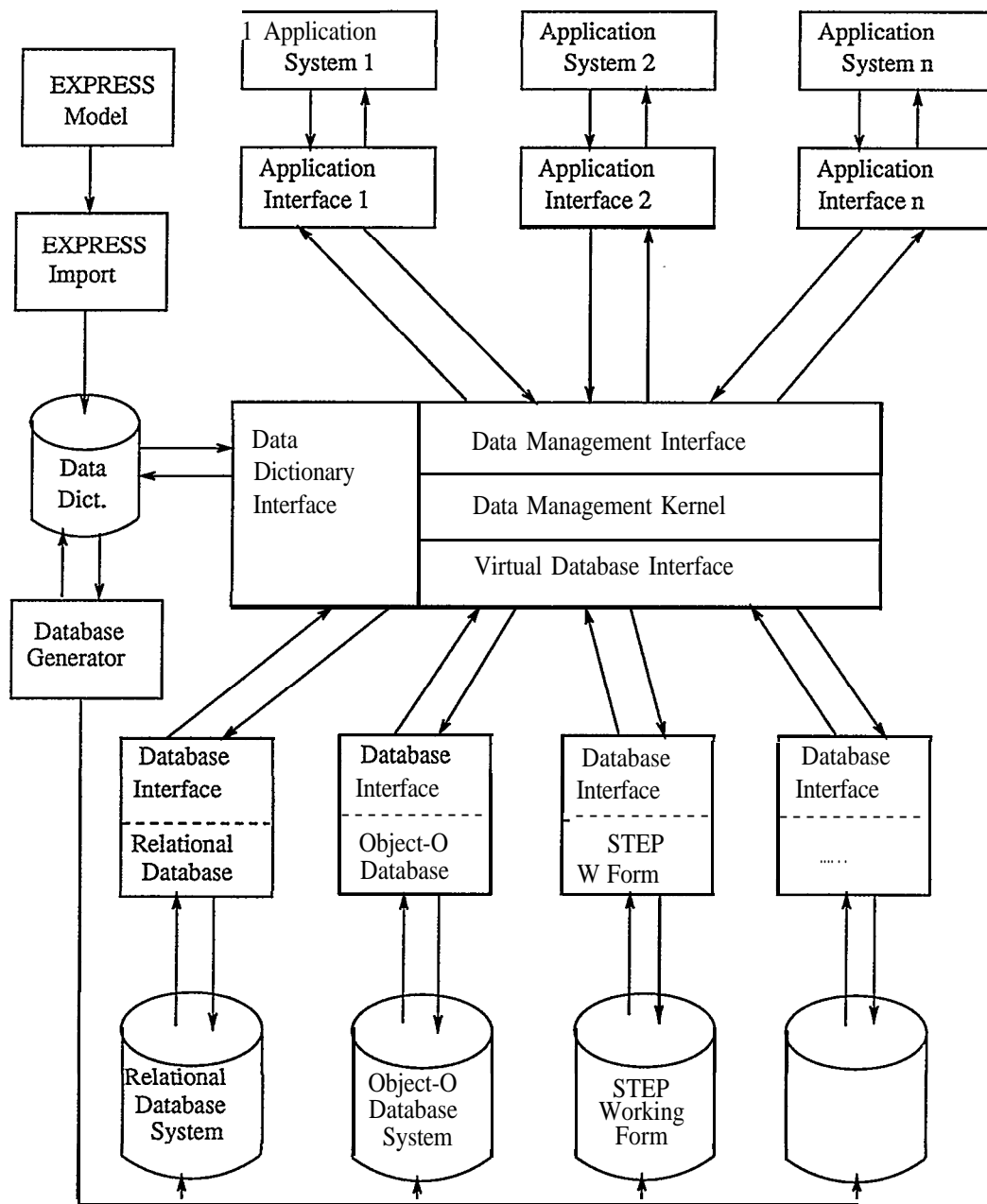


Fig.13 The NEUTRABAS system architecture.

application-independent store of product information. The main features and functions of each of these components are outlined in the following sections.

The EXPRESS model. This component of the system is the domain-specific information model which completely defines the shipbuilding product in terms of the information used to describe and represent it at each of its life-cycle stages. The model is independent of any application, and is written in the STEP information modelling language EXPRESS. The model itself will not be static, and will continue to evolve

over time.

The data dictionary. The data dictionary contains the dynamic form of the EXPRESS model described above. It comprises a formal definition of the structure of the data contained in the database, together with information concerning how the individual items of data are related to each other. The data dictionary allows requests to the database to be validated or it can alternatively be used to return the complete definition of the structure of an entity. This particular component can also be used to control security issues such as update rights, view rights,

versionning etc. for all of the requesting application systems.

EXPRESS import. The EXPRESS import facility is a software tool which maps from the EXPRESS-based product information model to the data dictionary defined in the above section.

The data management component (DMC). The data management component is effectively the core of the NEUTRABAS system. Its main tasks are to facilitate communication between the other components of the system and to convert requests in any one system-specific format to that of any other system. In order to carry out these tasks, the data management component consists of four main sub-components, as described below.

1. **Data Management Interface** - This is the external view of the NEUTRABAS system which contains a procedural interface to allow individual application systems to communicate with the neutral database.
2. **Data Management Kernel** - This component allows the creation, modification and querying of items of information by the connected application systems. To facilitate this, the data management kernel uses the data structure and relationship definitions contained in the data dictionary component described previously. Those requests received from the data management interface are reduced to more simple instructions by the data management kernel before being passed on to the virtual database interface.
3. **Data Dictionary Interface** - This allows the other elements of the data management component to query the data dictionary for detailed information on entities and their associated attribute structures.
4. **Virtual Database Interface** - This is a procedural interface which allows different database management systems (DBMS) to be connected to the NEUTRABAS system, in order to provide storage and data management facilities.

The application interface. The application interface is the specific interface which resides between a given application system and the neutral database. The interface itself may be one of two types. It may either be interactive or can simply consist of a pair of pre and post-processors, depending upon the nature of the specific application system being considered. The interface may be written in any high-level programming language providing that a suitable language binding is available.

The database interface. The database interface is the specific interface which permits communication between a particular database management system and the neutral database, and is a mapping of the virtual database interface onto an actual database system. Unlike the application interface, the database interface can utilize accepted database standards such as SQL (structured query language) for complete classes of database management systems. The database interface is a vital component of the NEUTRABAS system architecture, as it is intended that a NEUTRABAS product model will be capable of being stored in any commercial database system.

The database generator. The database generator is a tool which will map the definition of the product information model contained in the data dictionary to a specific database implementation. While performing this task it updates the data dictionary so as to provide information regarding the location of entities and their associated attributes in the actual database system. It is quite obvious that a separate database generator is required for each specific database management system being considered for connection to the neutral database. At present, consideration has been limited to the relational and object oriented database paradigms, together with the STEP working form file although it is hoped that other database types will be considered in the future.

THE PROTOTYPE IMPLEMENTATION SYSTEM

The previous sections of this paper have described various aspects of the information model of the shipbuilding product which has been developed to form the basis of the NEUTRABAS data exchange and storage system, together with a suitable architecture for the actual implementation of the system in the shipbuilding environment. In order to validate both the information model and the proposed system architecture it is necessary to perform some form of implementation to demonstrate the controlled exchange of product-related information between two or more disparate computer systems, and also to demonstrate the consistent time-independent storage capabilities of the NEUTRABAS system. Unfortunately, due to limitations on time and other resources, it is not considered feasible to implement a full version of the NEUTRABAS product model or attempt to produce all of the software tools specified in the system architecture. However, a significant subset of the complete product model specification will be implemented, as will the key software tools, in order to provide a realistic test environment for the NEUTRABAS approach.

Although the aim of NEUTRABAS is to facilitate the complete integration of all information systems in use at all of the product life-cycle

stages, for the purpose of validating the basic philosophy it has been decided to connect two, possibly three, different application systems to the NEUTRABAS system. The two definite candidates for this prototype testing system are CADIS, a steel structure design system, and CRESTA which is a production planning system. The third possible candidate is a preliminary ship design system named SPAN, which will be included in the validation exercise if resources permit. Even with only two application systems it will be possible to demonstrate how systems in different application areas, each having a different view of the product, can be made to communicate in an effective manner and share common information in a coherent and consistent way. Thus demonstrating that the true goal of a fully integrated product life-cycle is indeed one which could be achieved.

As previously stated, the testing system will involve the implementation of only a sub-set of complete shipbuilding product model. This sub-set will in fact comprise part of the steel structure of the cargo region of a container carrying merchant vessel, consisting of a number of prefabricated production units. It is considered that the selected sub-set contains sufficient entities from the complete model to provide quite a rigorous test of the NEUTRABAS philosophy in the area of preliminary and production-oriented design, and in the complementary area of production planning and control.

The ORACLE relational database management system has been selected to provide the means for the storage and retrieval of the physical data created and used by the application systems, although in theory any relational or object-oriented database system could have been chosen. At the time of writing this paper, work is currently being carried out on the implementation of the prototype system with its completion being scheduled for March 1992.

CONCLUSIONS

This paper has described some of the work being carried out on the NEUTRABAS project in the area of neutral data exchange and storage in the shipbuilding industry. The progress outlined in this paper has demonstrated the feasibility of achieving a truly integrated shipbuilding environment through the coherent and consistent storage and exchange of information relating to the product at all of the pre-commissioning stages in its life-cycle. An information model of the shipbuilding product which will accommodate the various views and information requirements of the many computer-based systems used in the European shipbuilding industry has been described. A neutral system architecture which will facilitate the implementation of this information model and

subsequently provide database management functions for the manipulation of the various product-related data created and used by the various application systems in use in the shipbuilding environment, has also been described. In addition, the proposed prototype implementation system which will demonstrate the application of the NEUTRABAS concepts in a working environment has been outlined.

NEUTRABAS is only one of many initiatives being carried out in the area of product data exchange throughout the world. It is, however, considered to be one of the leaders in this field and as such is actively contributing to the emerging international standard for the exchange of product data, STEP.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to all of their NEUTRABAS colleagues, past and present, for their contributions to the work reported in this paper. Gratitude is also expressed to the Commission of the European Communities (CEC) for their support of the NEUTRABAS project (No.2010) under the ESPRIT II initiative.

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Manufacturing Software for Shipyards

VB-2

Charles Zigelman, Visitor, National Steel and Shipbuilding Co.

ABSTRACT

shipbuilders (or any manufacturers, for that matter) are confronted with hundreds of choices of computer software for controlling manufacturing in today's market. The software, however can, be differentiated by certain salient features or assumptions which may or may not work in the shipbuilding environment. This paper will explore, in general terms, how shipbuilding is different (or the same) from other manufacturers in ways that are significant for the selection of these manufacturing computer systems. Some of the issues to be discussed are master scheduling, configuration management and project based production and inventory control.

INTRODUCTION

For 30 years, manufacturing companies have been using increasingly sophisticated computer software to control production.[1] This type of software, which is known in general as Manufacturing Resource Planning¹ (MRPII), is used to control the manufacturing process by controlling the material that goes into it. Over the years, software vendors have increased the sophistication of their product to match the improvements demanded by the market. These changes have in turn increased the range of manufacturers that have successfully implemented the product. The most notable in recent years have been a growing number of Aerospace and Defense (A&D) users. As shipyards struggle for a competitive edge, they are turning to

1 In the late sixties, the software only balanced supply and demand for material and so was known as Material Requirements Planning. The systems available *today* do this and much more. They are commonly called Manufacturing Resource Planning systems or MRPII.

the solutions successfully implemented in other industries. MRPII can be viewed as a simulation of the manufacturing process. To be useful it needs accurate data processed by a model that matches the real process. Though features and functions may be different, the MRPII model is now remarkably consistent across most software packages. The only major differences are between Aerospace and Defense and commercial business packages.

It is not the purpose of this paper to go into the details of the software selection process. There are already many excellent papers on the subject.[2] Rather, the purpose is to explore how well some of the assumptions in the MRPII model fit shipbuilding. The fit of these assumptions is much more important in the long run than the color of the screen, or how many keystrokes it takes to enter a transaction.

SOFTWARE SYSTEM BASICS

To understand the model, let us first explore the basics of how the MRPII software system works.

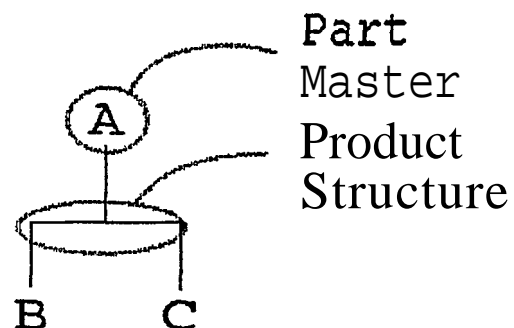


FIGURE 1

SINGLE LEVEL BILL OF MATERIAL

At the heart of the system is a bill of material. This bill is a hierarchical model of how a product goes together. It is made up of two major elements: part masters and product structure.

Part masters are the building blocks. They contain the attributes (characteristics) of an item that are common across all of its uses. Examples of these are part number, description, manufacturing or purchasing lead-time, weight, and group technology code. Product structure data shows how the part masters are linked together to make a particular product (Fig 1) Data usually included here is identification of the parent part number, the child or component part number and the quantity of the child needed to make one parent. Depending on the software system selected, these bills can have a virtually unlimited number of levels and constituent parts. At the top of the bill is usually the end product of the manufacturing process.

Once the bill of material has been defined, it can be used to plan and schedule work. This is done by introducing an order for the item at the top of the bill of material. This order is generally developed through a process known as Master Scheduling, in which the company decides, based on forecasts or actual customer orders, just how many of the end items it wants to build and when. Once the order is introduced, the system goes through the "netting and explosion" process. First, the system checks to see if there is any inventory for the item, either currently on-hand, or on order. Then this supply information is compared with the quantity and schedule of the demand. If it is sufficient, the process stops: if not, the system plans additional supply, either a shop order or purchase requisition. The quantity for the order is governed by lot sizing rules captured in the part master data. The schedule for the order is set by backscheduling from the due date using the lead times in the part master.

If the order is for an item manufactured in-house, the system "explodes" the bill to determine the material needed to complete the shop order. The explosion consists of reading the next level down in the bill to determine the list of components. These items are included on the order as the material list with a pick date backscheduled to support the manufacturing lead-time of the parent. The system then applies this new schedule and quantity information as additional demand for each of the components. This demand is in turn checked against any supply information for the components. In this manner

the system walks down each level of the bill of material creating a plan and schedule to meet the demand from the level above.

Software vendors usually sell their MRPII systems as a series of integrated sub-systems or modules. Once the orders are created by the planning modules their execution can be controlled by other sub-systems. There is a shop floor control subsystem to control the manufacturing orders through each of their workcenters. The purchasing subsystem is used to manage the conversion of the purchase requisition into purchase orders. A capacity management subsystem compares the plan to the capacity available at the workcenters. The last major piece is an inventory control subsystem used to manage the receipt and storage of inventory. Each subsystem or module is interdependent on the data from the other.[3](Fig 2)

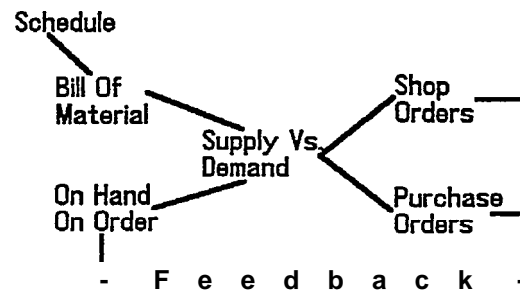


FIGURE 2

CLOSED LOOP SYSTEM

Many manufacturers may already use pieces of the MRPII model like a stand-alone shop floor control sub-system, or some kind of purchasing sub-system. Typically they don't "talk" to each other very well, so the data in the different sub-systems doesn't match. The key advantage of an MRPII system is that all these subsystems are linked together in a meaningful manner. If the users maintain accurate status of their activities, the MRPII system is capable of rebalancing the manufacturing plan based on updated status. This "closed loop" flow of information is the real strength of the system.[4]

With this simplified explanation in mind, the differences between some of the major underlying assumptions of the generic MRPII system and current shipbuilding practice can be explored.

SCHEDULING

The MRPII backscheduling algorithm is often compared with that of a Critical Path Method (CPM) network schedule. Indeed if the bill is turned

on its side it closely resembles a CPM network. This resemblance breaks down though because of one of the significant assumptions in the MRPII system. In a CPM network predecessor/successor relationship the occurrence of the predecessor event is sufficient to allow any number of successors to occur. In the parent/child MRPII bill relationship, however, there is always a specific quantity relationship built in. It is not sufficient for the child to simply occur; instead, it must exist (or be planned to exist) in sufficient quantity for each of the parents that require it. The assumption embedded in the MRPII system is that every item in the bill is a physical item that can be placed in inventory. In shipbuilding, this works fine for earlier stages of construction which deal with real items like pipe spools or steel sub-assemblies. It does not work as well for events that take place later in the construction cycle like test and activation milestones.

One result is that a ship's bill of material cannot be created down from a single end item representing the completed product. Unlike most manufacturing businesses, shipbuilding is a combination of conventional materials based manufacturing processes and unique project type construction activities like testing and activation of a particular piping sub-system. These construction activities do not fit the MRPII model because they require little or no material and the result cannot be stored in inventory.

The generic MRPII model drives the schedule through an end item representing the finished product. This is done with the support of an MRPII sub-system called Master Scheduling. The alternative emerging in A&D companies with products requiring extensive system testing is to integrate existing CPM network scheduling systems with MRPII. Instead of having a single bill of material to control all production activities, they

have many smaller bills each supporting an appropriate schedule milestone that is controlled by the CPM network.[5] The small bills of material control the purchasing, fabrication and assembly of physical interim products. The CPM schedule controls the testing and integration of these interim products into the final product (Fig. 3). Shipbuilders can conclude two things. First do not throw away network scheduling system. Second, do not expect to get much out of the Master Scheduling sub-system of MRPII.

PART NUMBERING

Another assumption in the MRPII system concerns part numbering. In MRPII the part master data lives in a single large file. This file is set up with the assumption that the part identities follow the rules of form, fit and function. These rules as applied are quite simple. They say that items with the same part number are always interchangeable, regardless of the revision level of the drawing that produced them - the "blind mechanics rule." Imagine a bunch of the items piled into a bin. A mechanic should be able to pull items out of the bin blindfolded and still get the right item.

Form, fit, and function are defined relative to the use of the item. Suppose an item is used as a component inside of a box. Since no one can see it, the color is not significant. Items with different colors could have the same part number, provided the qualities that were relevant to the application were identical. On the other hand, the color of components that can be seen is significant for a product that is differentiated by color[6].

Form, fit and function are also applied when an item changes its configuration due to a change of the drawing. If the rules are applied correctly, items that are no longer interchangeable get different part numbers. In other words, if the item defined by the new revision of the drawing is no longer interchangeable with the item defined by the previous revision, the new item must get a new part number. The MRPII system does not distinguish between the new item and the old item other than by part number.

A common mistake shipbuilders make in part numbering is assigning different numbers to items that are identical by form, fit and function. This is sometimes done to distinguish the parent item or shipboard location which an item is assigned. The MRPII system will tolerate this but it causes in-efficient planning. When the system

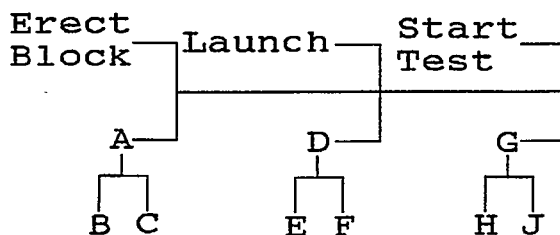


FIGURE 3

INTEGRATED SCHEDULE AND BILL

develops its material plan, it does so part by part. Each part number has its own set of inventory records and supply orders. While many systems have the ability to record group technology codes as part attributes, they are not used directly in developing the material plan. Therefore, it is to the advantage of the system user to assign identical items the same part number. Data about the particular usage of one of these identical items should be stored in the product structure link between that item and a particular parent. For example this data could include the specific compartment location and unique identity assigned to support Navy logistics systems. Unfortunately most generic MRPII software systems do not have enough room in their product structure data file to store all of the information required by shipbuilders.

It is important for shipbuilders to understand another aspect of part numbering. Items that are not the same cannot have the same part number regardless of what contract or design they were developed for. Unless the contract or class of the vessel is somehow explicitly included in the part number (making the part number different between different contracts or classes of vessel) the system will assume that items with the same part number are the same. All planning and scheduling will be done with the assumption that the items are physically interchangeable among all sources of demand. This is true of an MRPII system intended for the commercial market. A variant that is important to understand is the system that can do contract specific material planning.

CONTRACT SPECIFIC MATERIAL PLANNING

The standard NRPII system designed for commercial applications assumes that all in-process inventory is owned by the manufacturing company (an over-simplification but true enough for this explanation). Only after the end item is completed and shipped does ownership change hands. This means that not only are parts with the same number physically interchangeable (by form, fit, and function) but they can also be used for any order regardless of the customer which that order ultimately supports.

In shipbuilding, particularly for the Navy, this assumption could land you in jail. The Department of Defense, and many commercial shipbuilding customers, requires tracking ownership of the material long before the delivery of the end item. As a result, MRPII systems for the Aerospace and Defense market include

the ability to plan by contract. The material plan is prepared in much the same way as previously described with one major addition. The system now keeps track of the contract that caused each demand. Then, based on co-mingling rules defined to it, the system plans specific orders to support specific contracts or groups of contracts. It is important to remember that the form, fit and function rules still apply. The system still assumes that items with the same part number are physically interchangeable. In fact, items which support different contracts may still be stored in the same bin. It still does not matter which one the mechanic pulls out. The difference is that the system knows which contract's inventory to debit.

INVENTORY CONTROL

The MRPII model is based on manufacturing processes with a high degree of product discipline. It assumes that the parent item's identity is derived from the components that go into it. To illustrate how this affects inventory control assume there is a manufacturing order for a single parent item. At the start of the manufacturing cycle for the order there is no parent, just a pile of components waiting to be worked. At the end of the cycle there is the parent and no components; they have all been consumed into the parent. If the components are not all consumed, then the MRPII model considers that a symptom of one of two problems: either the bill of material is wrong, or the parent item specified by the order cannot exist. If the bill of material was accurate, but all the components were not consumed, then the parent cannot exist because its configuration is defined by the sum of all the components, not just the ones that happened to get used. Most commercial and many aerospace manufacturers hold to this assumption in a significant way. If all the components are not consumed, then the parent does not exist. The partially completed product will be delayed until it can be finished.

Compare this MRPII system assumption with shipbuilding practice. Following the National Shipbuilding Research Program (NSRP) terminology, suppose that a block is to have 35 pipe spools installed in it after blast and paint but before block erection.[7] The bill of material representing this plan would show the completed block as the parent and the 35 pipe spools as the components. If only 25 of the spools are actually installed, does the parent item "Block xx" exist? If the answer is yes, it does, a mismatch

exists between shipbuilding practice and the MRPII model.

In most MRPII systems, there are two kinds of places inventory can be: in a stock location available as on-hand inventory, or issued to a manufacturing order that is somewhere in process. Any parts not consumed by an order must be turned back into on-hand inventory to regain available status. If the order is statused as complete, then the system assumes that the real parent is available and interchangeable with any other item with the same part number. There is nothing in the system that automatically considers "This item A is almost the same as that item A, You just have to add on these items that should have been done earlier". There are ways to accomplish this feat. They involve using the change management portions of the MRPII system.

CHANGE MANAGEMENT

Change management for shipbuilding involves many issues beyond the scope of this paper. For most of these issues, the fit of the MRPII model is irrelevant. The exception is how the model handles the incorporation of changes to the bill of material. There are different approaches depending on the type of manufacturing the system is intended to support. On one hand there are make-to-stock consumer oriented manufacturers. They can design, then prototype the manufacture of a new item prior to starting mass production. Once the production line is rolling, there is relatively little change introduced.

On the other hand are design-to-order manufacturers like shipbuilders. A complex one of a kind product is engineered from scratch. The prototype goes into production even before all the engineering is complete. It is not an experiment that can be thrown away, it's a customer's valuable product. As problems in the design and production plan are revealed during the prototypes construction they must be fixed in a cost and schedule effective manner. These solutions must also be incorporated into any follow ships which are similar but rarely identical.

One way to view the life cycle of any product is to define three different bills through which it transitions: As-Designed, As-Planned, and As-Built. The As-Designed bill is the earliest view showing the engineering version of the content of the product. Typically, there is little or no production information associated with this bill. A good example of this in shipbuilding would be a system diagrammatic.

The engineering view is often not sufficient to plan and control the

material needed for manufacturing. The As-Planned bill rearranges the engineering view and adds production information. It includes an interim product breakdown, (which can be quite different from the way the drawing was organized) process and routing, tooling, and identification of additional production material such as jigs and fixtures. A pallet list which identifies all material needed to do the job is an example of an As-Planned bill.

Finally, the As-Built bill records how the product actually went together. This is where actual material identities and amounts used are recorded.

The MRPII systems designed to support design-to-order manufacturers will have the ability to store these different versions of the bill, while the standard systems do not. This gives the opportunity to maintain a drawing based engineering view (As-Designed) separate from a product based manufacturing view (As-Planned).

The As-Planned bill can also have two versions, the Class Plan and the Product Specific Plan. These represent the difference between goals and reality. The Class Plan is the way we would imagine the ship should go together. It assumes a nearly perfect world, where all the engineering is done, the material is all bought and available, the necessary manning and facilities are ready, and relatively little change is being introduced into the bill. One way to envision the Class Plan is to think about how to build the fourth or fifth commercial ship in a class.

Unfortunately after Class Plans are set in motion, the Product Specific Plan is needed to take account for reality on a specific hull. When engineers make changes to their drawings they usually think of the changes as Class Plan changes. That is, the engineers do not consider where in the construction cycle the ship actually may be; they modify the drawing to show how the ideal ship should go together.

The production plan, on the other hand, must reflect the status of the ship. If more than one ship in a class is under construction for example, a change may be implemented on different interim products for different hulls depending on each hull's status.

There are different ways to handle change in the As-Planned bill, particularly if more than one hull is involved. To understand this difference one more bill type must be introduced, the order bill.

In all MRPII systems, regardless of the type of manufacturing they are designed to support, the material based

production plan is captured as the multilevel As-Planned bill. The execution of the plan is governed by orders, either manufacturing orders or purchase requisitions. These orders are created as a result of the previously described explosion process: the system reads the next level in the bill of material to determine the material list. This data is stored in a separate file and is called the "Order bill."

There are a number of options in the way the system interprets the As-Planned bill to create the content of the order. These options are known as "effectivity rules". Some rules are intended to support the make-to-stock environment, some the design-to-order. Different MRPII systems will have different sets of rules embedded in them depending on the type of manufacturing they are intended to support.

The simplest rule is "What you see is what you get." It means what it says: the content of the Order bill equals the content of the As-Planned bill at the moment of explosion. If something is added to or deleted from the As-Planned bill after explosion, there is no way to tell what the difference is other than by a line by line comparison of the old bill to the new.

A refined method of controlling effectivity is by date (Fig. 4). This means that items added to or deleted from the As-Planned bill have an "effectivity date" associated with them.

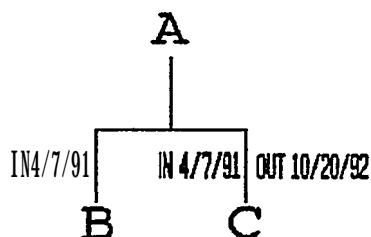


FIGURE 4

DATE EFFECTIVE BILL

This date indicates when the change should be included in the explosion process. It allows currently effective segments of the As-Planned bill to coexist with other segments that are not yet ready to be used. The system compares the date when the order will be used with the effectivity dates of the As-Planned bill and reads only those segments that should be included. A user can inquire into the As-Planned bill and see the old and new views

simultaneously to understand the magnitude of any change. Each change in the MRPII system must be associated with a specific change authority before it can be entered. The change authority is the number of the document that authorized the change like an Engineering Change Notice (ECN). Since a change authority is associated with each bill revision the user can trace each bill change to the piece of paper that authorized it.

The problem with date effective bills in the shipbuilding environment is that it can be difficult to manage the dates. In the make-to-stock environment it is relatively easy to pick a date when a change should take place. Then the change is cut in simultaneously for all products in process on that date. In shipbuilding the change may take place on different dates for different hulls depending on a number of factors like material availability and fit with the production plan. Even more difficult to manage is changing the date in response to schedule changes. Shipbuilders, along with many design-to-order users tend to think in terms of the end item for which the change is effective; not a particular date. In other words, shipbuilders may say, "For Hull A we'll do it prior to launch, but for Hull B we'll do it after." This way the user does not have to specify in advance the date that a change will be effective, only the interim product that will change. This technique is known as end item/serial effectivity (for the "serial number" of the end item, like hull 100, Fig. 5). When the order is created, the system knows the end item or hull that it is for and chooses the segments of the bill accordingly.

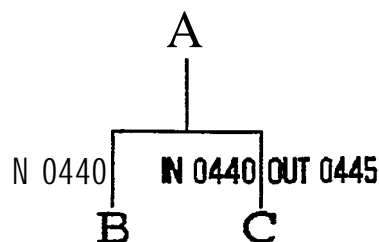


FIGURE 5

END ITEM EFFECTIVE BILL

This effectivity method also has a change authority associated with it.

CONCLUSION

Shipbuilding is manufacturing. It may be different but it is not so

different that it cannot take advantage of modern materials based manufacturing software.[8]

Manufacturers confronting the decision whether to use any packaged MRPII software usually have two alternatives. One is to continue to use the hodgepodge of homegrown software systems that have grown up in the company over the years. The users in each area of the company have grown quite comfortable with "their" system. Unfortunately "their" system either doesn't talk to anyone else's or has redundant but slightly different data than the other company systems. Either of these possibilities makes the efficient interchange of information across organizational boundaries difficult.

The other choice is to attempt to design and program a software system from scratch. This choice is prohibitively expensive for a system of the size and complexity of a modern MRPII system.

No packaged software system will match shipbuilders or any other manufacturers requirements perfectly. A company gives away a perfect match to the needs of any of its individual pieces. It gets in return an integration that helps tie together all the pieces. This integration, built around a well tested model incorporating good manufacturing practices, is an important competitive edge for American shipbuilders.

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Zone Technology Implementation at Philadelphia Naval Shipyard - Phase III

VIA-1

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ABSTRACT

Phase One implementation of Zone Technology at the Philadelphia Naval Shipyard (PNSY) began with the planning of the Service Life Extension Program (SLEP) of the USS Kitty Hawk ((CV-63) in 1986 with the assistance of Japanese engineers from Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI). Phase Two of Zone Technology implementation included the continuing work on the USS Kitty Hawk, extensive planning efforts for the USS Constellation (CV-64) SLEP, and the execution of a number of smaller availabilities. Phase Three of Zone Technology consists of the completion of the USS Kitty Hawk SLEP, the final planning and commencement of the USS Constellation SLEP utilizing 100% Zone Technology, and the planning and execution of all future availabilities utilizing the concepts of Zone Technology.

Significant lessons learned from prior availabilities, particularly the USS Kitty Hawk, have been identified and implemented on the USS Constellation SLEP. Results from smaller availabilities have been encouraging and are presented. Initial comparisons between the USS Kitty Hawk and the USS Constellation SLEP work performance in cost and schedule are reviewed.

ACRONYMS AND DEFINITIONS

AIM: Advanced Industrial Management. U.S. Navy program to integrate the development and implementation of technical work procedures and related naval shipyard improvements.

CALS: Computer-Aided Acquisition and Logistics Support. The Department of Defense initiative to automate and integrate the generation, maintenance, and use of weapons system technical information.

CPI: Cost Performance Index. The (CS)² term representing the ratio of expenditures versus physical progress budget on completed work and work in

progress.

(CS)²: Cost/Schedule Control System. Shipyard computer system to track expenditures and physical progress versus budget and time allocations for authorized work.

DSR: Design Service Request. The formal method where the Production Department requests engineering assistance from the Design Division.

FON: Fiber Optic Network. A specific type of LAN utilizing fiber optics as the physical link between stations.

KEOP: Key Operation. The lowest level non-trade unique, work instruction.

LAN: Local Area Network. The term utilized to describe the actual hardware and software link between computer systems and work stations.

LOE: Light Off Exam. The exam which determines the capability to safely operate the propulsion plant on a U.S. naval vessel.

PF: Performance Factor. The ratio of expenditures versus allowances (normally on completed KEOPs).

PQP: Philadelphia Quality Process. The Philadelphia Naval Shipyard's version of Total Quality Management/Leadership.

SARP: Ship Authorized Repair Package. The contract between the shipyard and the customer concerning the repair and overhaul of a specific ship.

SHIPALT: Ship Alteration. An authorized alteration to a ship system or configuration of a U.S. naval vessel.

SIMA: Shore Intermediate Maintenance Activity. A military activity designed to support emergent and scheduled non-depot level repairs of U.S. naval ships and other vessels as appropriate.

SLEP: Service Life Extension Program. An overhaul program to increase the

service life of conventionally powered aircraft carriers by 15 years.

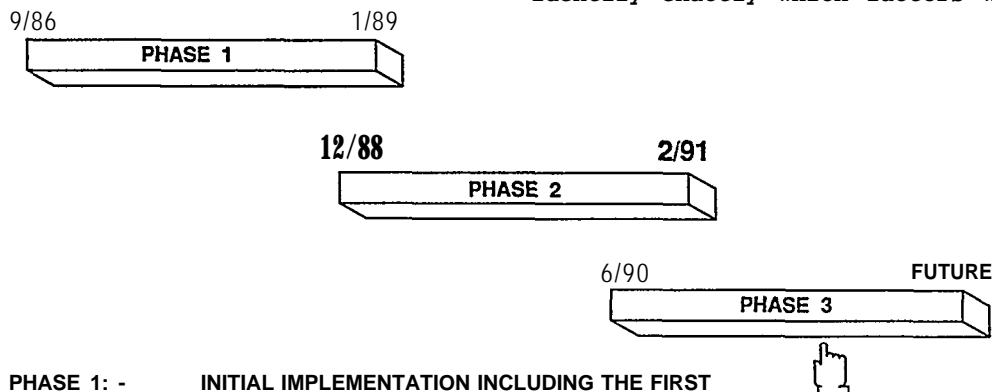
SYMIS: Shipyard Management Information System. The term utilized to describe the variety of common shipyard computer information systems.

WES: Work Estimate Sheet. The initial estimate of work in man hours by the Planning and Estimating Division based on the authorized work in the SARP.

WMT: Waterfront Management Team. A group of production, planning, supply, and other department personnel directly supporting the execution of a ship overhaul.

INTRODUCTION

The Service Life Extension Program for the USS Kitty Hawk (CV-63) has been completed. Implementation and execution of Group Technology/Zone Technology for a major portion of that availability is discussed in detail by Baba et al, (1) and Burrill. et al (2). The shift from a ship work breakdown structure to a product work breakdown structure began in 1986 and is still far from complete. The immediate change in repair philosophy utilized in part on the USS Kitty Hawk was culturally difficult. To summarize the enormous amount of work that has been accomplished since 1986 toward the transition to product oriented philosophy would only over-simplify the difficult changes in processes that were made. The purpose of this presentation is to provide information on the shipyard's current process for the planning and execution of the USS Constellation SLEP and other scheduled availabilities utilizing Zone Technology concepts.



- PHASE 1: - INITIAL IMPLEMENTATION INCLUDING THE FIRST YEAR OF EXECUTION ON USS KITTY HAWK
- PHASE 2:- PLANNING PHASE FOR USS CONSTELLATION SLEP, COMPLETION OF USS KITTY HAWK SLEP AND EXECUTION OF USS SPRUANCE AND USS HEWES
- PHASE 3:- EXECUTION OF USS CONSTELLATION SLEP IN CONJUNCTION WITH OTHER COMPLEX OVERHAULS / AVAILABILITIES

Figure 1 depicts the planned phases of Zone Technology implementation. Table 1 illustrates the projects that have been executed utilizing Zone Technology principles with the approximate number of production man days of work assigned to each. Table 1 also highlights future projects that will be executed utilizing Zone Technology.

Phase III of Zone Technology implementation at PNSY is in its final stages. By September 1991, the USS Constellation (CV-64) SLEP will be approximately 50% complete. The USS Detroit (AOE-4) overhaul will have just been completed, and a total assessment or audit of the shipyard's Zone Technology processes will have been completed. Analyzing the results of this assessment and taking corrective action, combined with future Zone Technology initiatives, comprise Phase IV of Zone Technology implementation.

COMPLETION OF USS KITTY HAWK CV-63

Results from the USS Kitty Hawk SLEP are inconclusive in that the success or failure of the Zone Technology process cannot be statistically determined to a significant degree. The USS Kitty Hawk SLEP performance was average as shown in Figure 2; the productivity improvements that were expected to result in cost savings were not realized. Considering the monumental shift in repair philosophy, the tough cultural barriers that had to be overcome, and the large scope of new work and growth that was authorized late in the overhaul, it is remarkable that the performance of the USS Kitty Hawk SLEP remained as close to the average as it did. It remains a formidable task (if even possible) to identify exactly which factors were most

Fig. 1. ZONE TECHNOLOGY IMPLEMENTATION PLAN

<u>PROJECT</u>	<u>PRODUCTION MANDAYS</u>	<u>STATUS</u>
USS KITTY HAWK (CV-63)	550,000	COMPLETE
USS HEWES (FF-1078)	15,000	COMPLETE
USS SPRUANCE (DD-963)	15,000	COMPLETE
USS CONSTELLATION (CV-64)	725,000	IN PROGRESS
USS DETROIT (AOE-4)	35,100	JUNE 1991
USS WISCONSIN (BB-64)	30,000	OCT 1991
USS FORRESTAL (CV-59)	374,000	SEPT 1992
USS JOHN F. KENNEDY (CV-67)	700,000	SEPT 1993

Table 1. ZONE TECHNOLOGY PROJECT STATUS

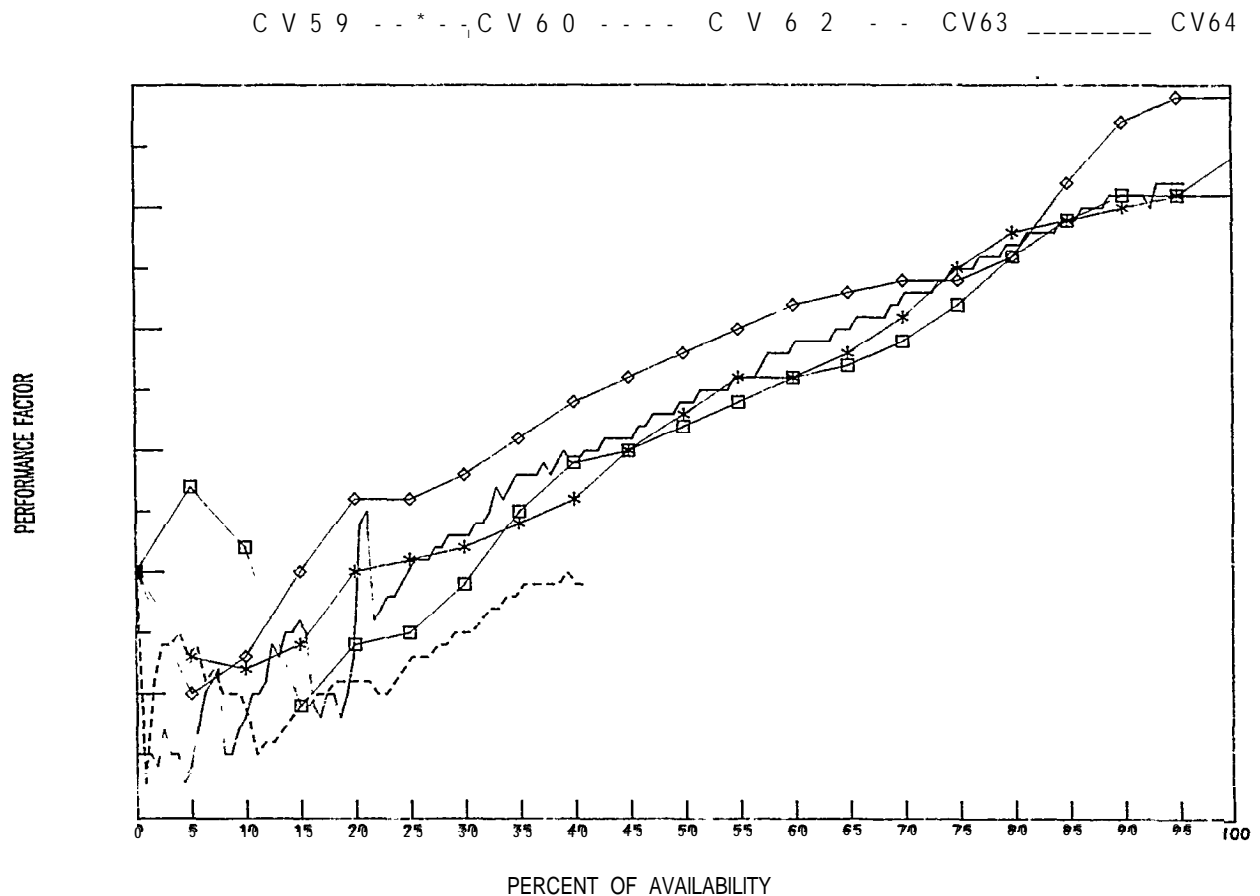


Fig. 2. AIRCRAFT CARRIER SLEP PERFORMANCE FACTOR

responsible for not realizing significant cost savings, however two general causes were discussed in reference (2).

1. General upward and downward communication difficulties.
2. Failure to involve all levels of management in the planning and execution decisions of Zone Technology implementation.

The corrective actions taken by shipyard management during the SLEP were effective in limiting disruption for the remainder of the USS Kitty Hawk overhaul. What will be emphasized for this presentation are the new processes that have been established to improve the shipyard's ability to execute a major availability utilizing a product work breakdown structure.

PHASE III IMPLEMENTATION OF ZONE TECHNOLOGY

Preliminary

The majority of the fundamental principles of Zone Technology remain in place in the shipyard's planning and execution philosophy. Baba, et al (1) discuss those principles at length. Burrill, et al (2) discuss what changes were deemed necessary as part of the shipyard's evolution. This discussion of Phase III execution incorporates additional initiatives that have not been previously presented.

Waterfront Management Team (WMT)

As part of incorporating lessons learned from prior overhauls, a production support team or Waterfront Management Team (WMT) was formed for the USS Constellation SLEP execution. Figure 3 depicts this WMT organization. As a matter of policy it was determined that the Waterfront Management Team will always be located near the ship, and will be outfitted with adequate computer support via the shipyard's fiber optic local area network. What follows are the general responsibilities of each member of the WMT.

Zone Manager. The Zone Manager is a senior Production Department individual permanently removed from the shop organization. This individual is personally responsible for successful execution of the assigned zone in cost and schedule. For a SLEP, the Zone Manager is normally equal to the level of Chief General Foreman of a production shop. Zone Managers are fully responsible for production coordination and are assigned as the "chairmen" of the Waterfront Management Teams.

Ship Superintendent. The Ship Superintendent is a military or civilian manager who is responsible for ship's force liaison and safety. The principal function that this individual performs is the integration of ship's force work into the shipyard production schedule. The Ship Superintendent also coordinates the

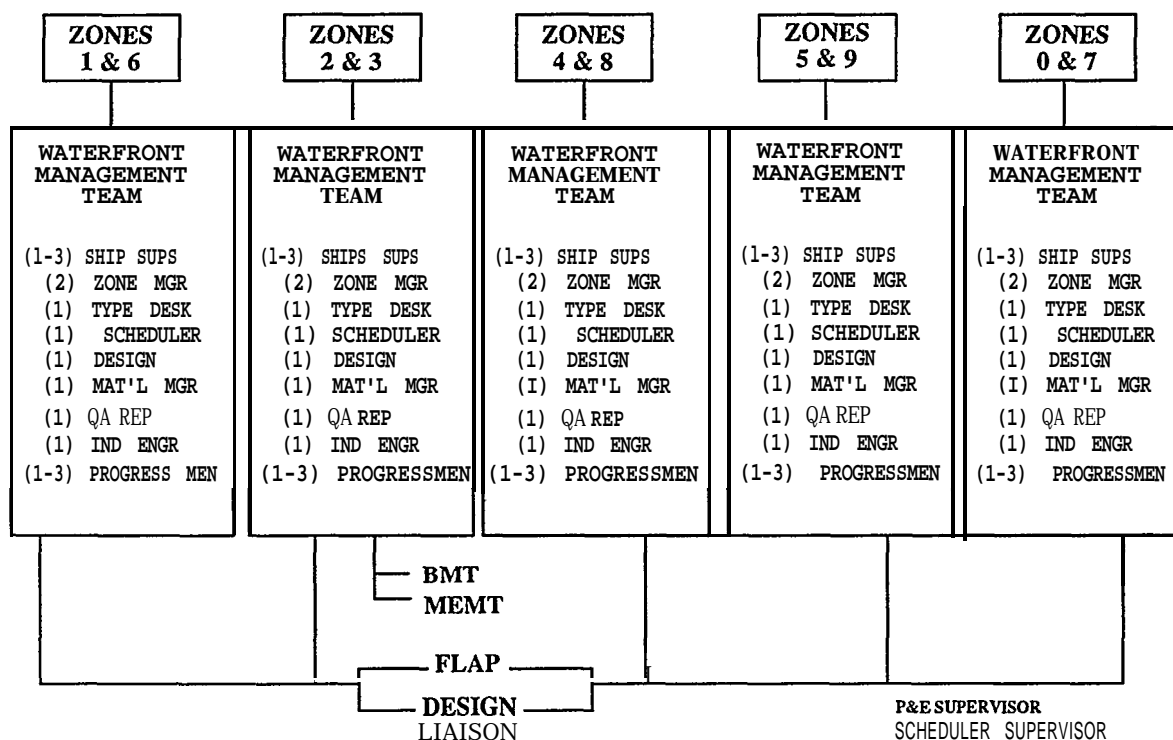


Fig. 3. WATERFRONT MANAGEMENT TEAM COMPOSITION

integration of all other miscellaneous repair work performed by outside repair activities such as Shore Intermediate Maintenance Activities (SIMA), other shipyards, and other government agencies, into the production schedule.

Type Desk. The Type Desk is the single point of contact with the customer. The Type Desk acts as the funds administrator for the assigned zone. This individual is responsible for risk assessment and has the authority to authorize new work or growth based on this assessment within the overhaul objectives. The Type Desk is the Planning Department's representative to the Production Department for that particular assigned zone. The Type Desk member reports to the parent division administratively and to the Zone Manager functionally concerning the planning and execution of the project. This member of the WMT identifies cost variances to management before they become a major problem. The Type Desk member is linked to the main Type Desk financial computer via modem.

Scheduler. The Scheduler is the individual responsible for the maintenance of the entire Production Department schedule for that zone. This individual identifies events that are behind or ahead of schedule for review and possible correction. The Scheduler provides the Zone Manager and other Production Department managers the short term production schedule which is a bar chart of all work packages scheduled to start, work, and complete within a 90 day window. The Scheduler is linked to the main scheduling computer via modem.

Industrial Engineer. The Industrial Engineer is responsible for assisting the Zone Manager and other members of the Waterfront Management Team with industrial engineering matters such as time studies, engineered methods and standards, and work processes. The assignment of an industrial engineer to each WMT is a commitment by the shipyard to more actively involve these individuals with the day to day production problems in an attempt to permanently resolve them for future availabilities.

Progressman. The Progressman assists the Zone Manager and other members of the Waterfront-Management Team in auditing physical progress on outstanding and completed work. A "trouble-shooter" for the Production Department, this individual reports the detailed status of specific jobs to the Zone Manager. This individual assists the Production Department in compartment turn over to ship's force where applicable.

Material Manager. The Material Manager acts as the single SUPPLY Department representative to the Production Department for that zone. This individual is responsible to the Zone Manager for all supply issues related to the project. The Material Manager is linked to the shipyard's material management computer system via modem.

Planner. This individual is the first point of contact for the Production Department in resolving funding requests for unforeseen or overlooked circumstances discovered during the execution of the work. The Planner assists Production Department personnel with planning and estimating concerns. The Planner receives the authority to issue work from the Type Desk member of the WMT.

Design Representative. This member of the WMT belongs to the Design Division's waterfront liaison branch. This individual investigates technical problems at the job site and gives verbal guidance to the mechanic or foreman in order to allow work flow to continue as appropriate. When technical issues require more detailed study, they are walked to the appropriate branch of the Design Division and given a priority based on urgency and complexity of the issue. The Design Division is normally required to answer "work stoppage" technical issues in 24 hours or less.

Ship's Force Representative. This individual acts as the single point of contact for the Waterfront Management Team when dealing with ship's force issues for that zone. This member, although not residing in the trailer on the water front, works closely with the Ship Superintendent to resolve schedule conflicts between ship's force and the Production Department.

Zone Manager's Desk

Supporting some of the Advanced Industrial Management (AIM) and Computer-Aided Acquisition and Logistics Support (CALS) initiatives, the Zone Manager's desk was developed to provide a realtime easy-to-use production management and coordination tool for all levels of management in the shipyard. O'Hare and Anderson (3) detailed the complex and technical arrangements surrounding the installation of the shipyard's fiber optic Local Area Network (LAN). This fiber optic network physically links most of the major Planning Department and many of the Production Department offices directly to the WMT trailers located next to the ship. Obtaining data from the Shipyard Management Information System (SYMIS) resident in the Honeywell computer, as well as the variety of other computer systems, menu-driven management products can be provided to production

managers that are specifically tailored to their needs. The Zone Manager's desk is one feature that is available on the LAN to every member of the WMT, general foremen, shop and project managers, the Production Officer and the Shipyard Commander, among others. A variety of products are currently available to shipyard and ship's force managers via the Zone Manager's desk for all Zone Technology availabilities.

Compartmentation. This feature allows the user to select any compartment and identify what authorized shipyard and ship's force work is scheduled in that compartment and what the status of that work currently is. Although work by geographic area has always been available to management since the inception of Zone Technology, the detail of work generally ceased at the subzone level as defined by Baba et al, (1). The compartmentation data base brings this detail one step further. The program provides ship's force and shipyard managers the capability to validate compartment turn over electronically rather than the extremely expensive, manpower intensive turn over program *utilized on prior SLEPS*. Although this program will never replace a space walk-through, it is a useful management tool.

The shipyard compartmentation data base is not 100% accurate since the individual compartment where work is performed is currently not a mandatory field on the shipyard's Work Estimate Sheets (WES), scope sheets, or actual work instructions. Although the compartment where the majority of work is performed is often available on these documents, and always on the drawing included in the work package, it usually does not mention minor compartments or spaces that are affected incidentally by hot work or insulation removal. In order for this program to be fully effective, the compartment(s) field must be a mandatory entry on all planning documents: this is a future Zone Technology initiative.

Gains are continuing to be made to improve the accuracy of the compartmentation information currently available. Programs that scan narrative comments on issued work instructions for compartment indicators have improved the database dramatically. A fundamental push for the planners to include all affected compartments as a part of the work package will drive the confidence level even higher. Electrical cable installation for cables that pass through many zones is an area where particular success has been achieved: The compartmentation program will show when a cable originates, terminates, or simply "just passes through" any particular compartment of interest. This capability is an enormous help to production

managers and ship's force as they progress through the overhaul.

Event Management. This feature allows the user to view SYMIS data by zone or total project within the schedule event hierarchy. The user can view this information at the Key Event (A) level and within a few seconds select down to the Milestone (B), Work Package (C), Key Operation (KEOP), or even line item (trade skill) level. All MIS data normally available is viewed on the screen or printed: information is updated weekly from the Honeywell computer. This capability represents a major revolution at the shipyard in information management. Shipyard managers may now spend only a few minutes reviewing data for specific problem areas rather than a much larger time reviewing all paper reports and then pulling out the schedule and cost problem areas to investigate in further detail. Now, focus is made only on areas that require attention--or "management by exception." This feature is essentially an "on-line" Cost Schedule Control System (CS) program.

Also available on the LAN, is the ship's force work package structured within the shipyard event hierarchy. The automated integration of ship's force and shipyard schedules represents a significant improvement in the shipyard's ability to coordinate shipyard and ship's force work. For the USS Constellation SLEP, this integrated schedule is a critical management tool since the ship's force work package is approximately 262,000 man days of work as compared to the 725,000 man days of shipyard work.

Management Information System Information. This program allows the user to select any job order/KEOP to view current MIS information independent of schedule events and is primarily a financial tool that is necessary because the Ship's Alteration and Repair Package (SARP) is still organized financially by system rather than by zone.

Production Organization

Since the shipyard first commenced Zone Technology implementation, the Production department has undergone numerous changes. The Zone Technology Group (Code 940) was absorbed into the Structural Group (Code 920) during the execution of the USS Kitty Hawk SLEP. The "polarization" of the shipyard or "two shipyard syndrome" was the principal reason for this change in structure. As the Philadelphia Quality Process (PQP--the shipyard's version of Total Quality Management) gained momentum, it was apparent that paths of communications within the shipyard (formal and informal) had broken down. The separate Zone Technology Group aggravated this

breakdown of communications. Unfortunately, along with the dissolution of this production group, product trades were also dissolved. Without true product trades, it is extremely difficult, if not impossible, to make significant and lasting productivity improvements utilizing an interim product philosophy in the repair and conversion of U.S. naval ships.

The value of product trades did not go unnoticed, however, and now that Zone Technology has gained much wider acceptance, the Production Department is gradually evolving back to the product trade concept, only in a more culturally "acceptable" manner. Figure 4 depicts the current functional Production Department organization.

In reviewing the organization charts from reference (2) you may notice that the Pipe and Boiler Group (Code 960) has been eliminated. Code 960 was comprised of pipe insulators (Shop 57), pipe fitters (Shop 56), and boiler makers (Shop 41). Shop 57 was incorporated into the Service Group (Code 970) where bulkhead insulators (Shop 64), who complete a similar product, currently reside. Shop 56 was incorporated into the Structural Group (Code 920)--based on their product relationship with the welders. Shop 41 was incorporated into the Mechanical Group (Code 930) since Code 930 was always ultimately responsible for the main engineering

space's principal product: a successful Light Off Exam (LOE). Boiler work often *emerges* as the critical path for main engineering space work during an aircraft carrier SLEP.

The ideal Production Department organization should ultimately become a total "product" organization and could likely see the department slim down to three groups: Mechanical Product Group, Hull/Structural Product Group and Electrical Product Group. The Service Group would naturally disperse to "service" the other groups in the achievement of their individual product goals in cost and schedule. In the IHI Tokyo shipyard (reference 4), as a comparison, there are only three fitting shops: hull fitting, machinery fitting, and electrical fitting. The average mechanic retains several common skills such as minor rigging, burning, cleaning, etc.

Project Management

Many of the public Naval Shipyards have evolved in some degree towards a Project Management style of repair philosophy. Figure 5 details the Project Management structure for the USS Constellation SLEP. Code 300C is a Group Superintendent removed from the Group organization and dedicated 100% to the success of the USS Constellation SLEP. The project manager has been provided a warrant from the Production Officer and

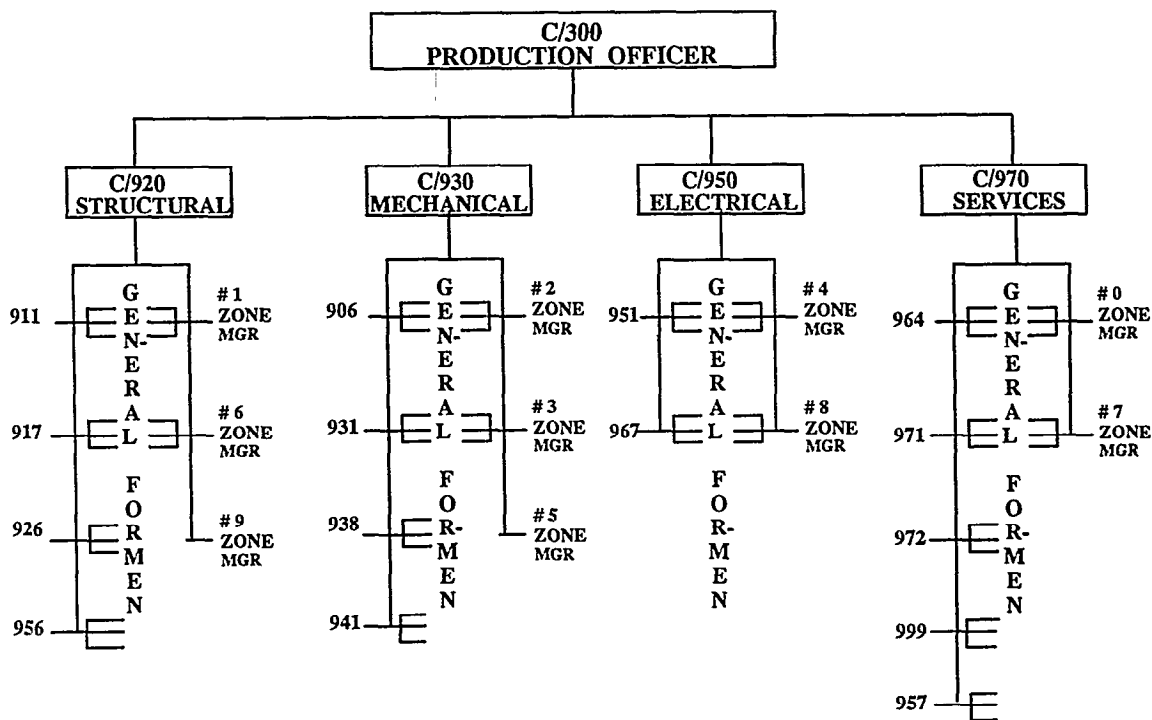
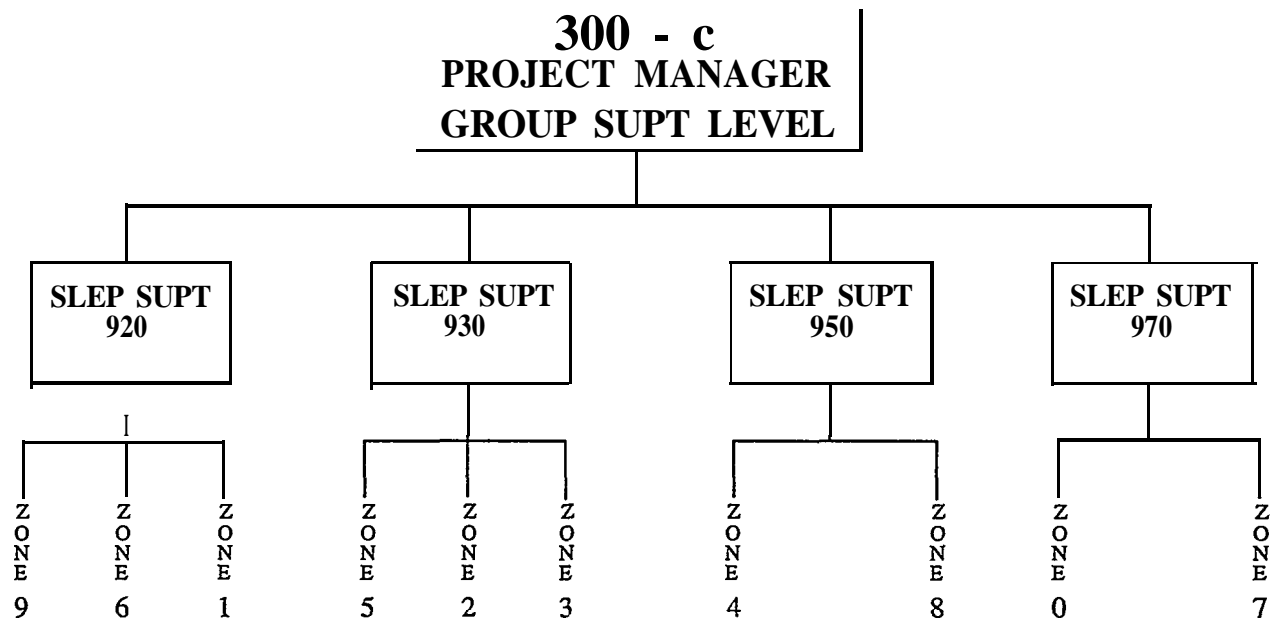


Fig. 4. PRODUCTION DEPARTMENT ORGANIZATION



ZONE MANAGERS

Fig. 5. SLEP PROJECT MANAGEMENT ORGANIZATION

has been granted full authority over the entire Production Department with regards to the USS Constellation overhaul, including indirect labor divisions that fall under the Production Officer's cognizance. For the USS Constellation SLEP, the project manager has line authority over Group Superintendents, SLEP Superintendents, Zone Managers, and production shops. The project manager also has the influence to control manning on all shifts and provides specific recommendations to the Repair Officer in the assignment and control of overtime. The Zone Managers have "directing authority" over production managers assigned to their zone.

Directing authority has been defined as absolute line authority for one day. Production personnel must comply with a directive from the Zone Manager until, if there is a conflict, formal resolution can come from the senior project manager or Production Officer, if necessary, the next day. Since there have been no "conflicts" during the USS Constellation SLEP thus far, perhaps "perceived authority" is as effective as permanent authority. Military ship superintendents have been taking advantage of "perceived authority" for years in public naval shipyards. It is recognized that "directing authority" is not the most efficient form of management, yet is a step in the right direction and prevents the Zone Manager from becoming bogged down with the myriad details of personnel management that normally accompany line authority.

Figure 6 details the project management structure for the USS Detroit overhaul. A shop head level production manager normally will be taken off-line to act as senior project manager for a smaller availability. The Zone Manager of a smaller project is normally a General Foreman level manager. The critical step for the smaller availabilities is that the general foreman level Zone Manager is "divorced" from the parent shop. This separation from the shop organization is vital because that individual is no longer a functional manager who is naturally more concerned about shop performance rather than project performance.

Measurement of the Integrated Planning and work Packaging Process

One of the fundamentals of Total Quality Management and the Philadelphia Quality Process is the theme of continuous improvement. Measurement of integrated planning efforts for production, highlights not only the shipyard's ability to efficiently execute day to day processes, but its ability to correctly execute Zone Technology as a productivity enhancement. On a biweekly basis the senior shipyard managers review measurement indicators which enable an assessment of our planning and execution success (or failure) on a Zone Technology availability. As an example, Figure 7 depicts the inability (although on an improving trend) of Code 360 (Hull, Propulsion, and Auxiliary Test Division) to issue all test procedures 150 days

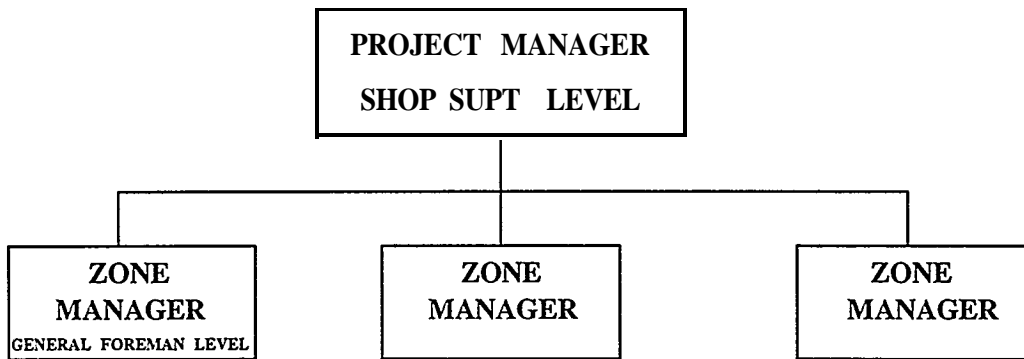


Fig. 6. SMALL AVAILABILITY PROJECT MANAGEMENT

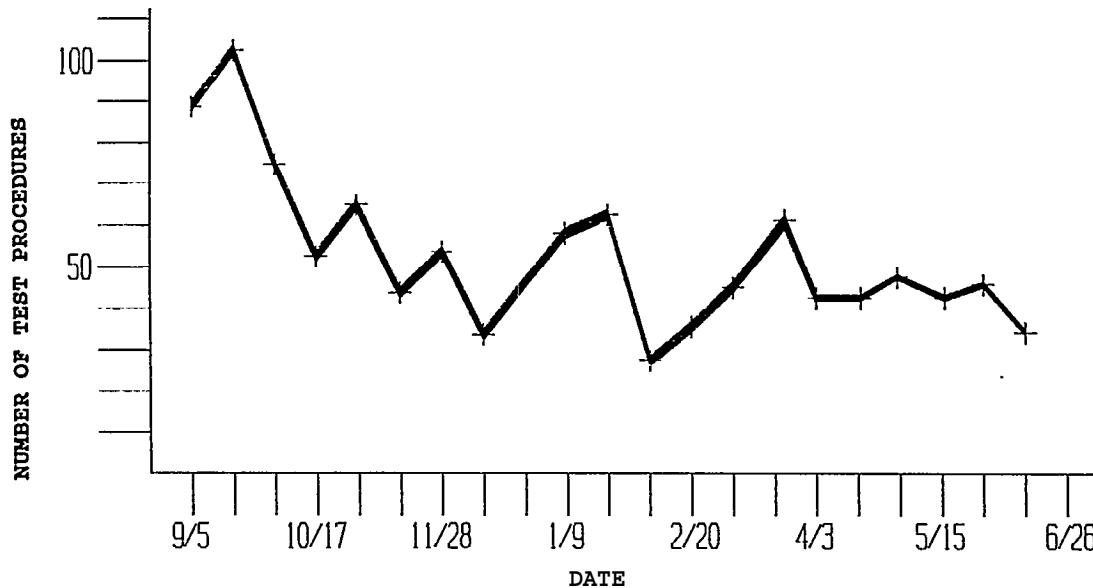


Fig. 7. TEST PROCEDURES THAT ARE NOT ISSUED 150 DAYS PRIOR TO THE START OF THE WORK PACKAGE

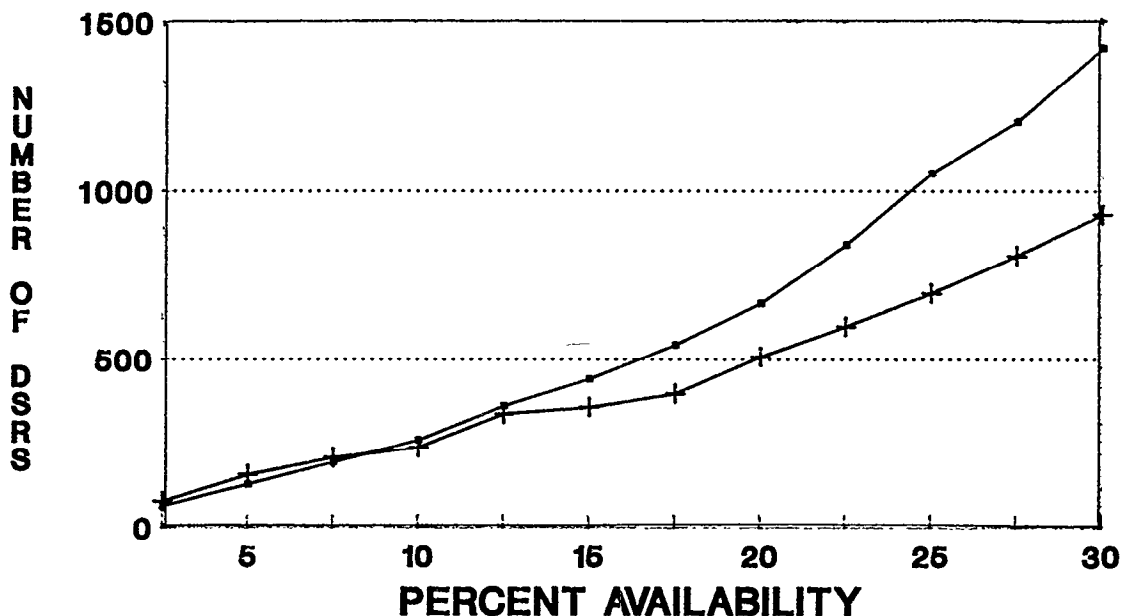
prior to the start of a specific work package. Every two weeks, this detailed scrutiny occurs for all production supporting shops and codes. Examples of other measurements:

1. The total number of shop reports that have not been answered within the five day requirement.
2. The total number of Design Service Requests (DSR) that have not been answered in the required 24 hours that are holding up production work.
3. The number of work packages that exceed 1200 hours in duration and are less than 200 hours in duration. It is commonly believed that smaller more manageable units of work

are more easily executed. The shipyard has established a target of approximately 800 hours for each work package.

4. The number of work packages that have been re-scheduled to the left and to the right.

The DSR issue is one measurement indication that the shipyard's integrated planning efforts are having a positive impact. Figure 8 depicts the total number of DSR's submitted on the USS Constellation SLEP work and how that number compares to the USS Kitty Hawk SLEP. The number of DSRs submitted by production can often be correlated to the total number of man days in the authorized work package. Accordingly, the USS Kitty Hawk SLEP DSR numbers were reduced by 37% to reflect the smaller USS Constellation SLEP work package. Even



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Fig.8. DESIGN SERVICE REQUEST SUBMISSION

with that adjustment, the number of design questions that are being asked is 35% lower on the USS Constellation SLEP than on the USS Kitty Hawk SLEP for the same period of the availability. Many reasons can be attributed to this trend, among them:

1. Aggressive design engineers on the water front as part of the Waterfront Management Team, verbally correcting minor design issues as they arise.
2. Integrated Design Packages.

Integrated design packages are three dimensional CAD drawings that consider all authorized ship alteration work in an area with respect to ventilation, piping, electrical cableways, machinery arrangement, and existing ship conditions with respect to interference control. These packages are expected to "pay for themselves" by significantly reducing the number of DSR's on the 25 selected compartments for the USS Constellation SLEP.

The customer for this entire evolution is the Work Packaging branch (Code 229). Code 229 is responsible for issuing a work package to production 90 days prior to the scheduled start of the work. The work packaging branch, as the customer, reports on the performance of its suppliers to deliver the products necessary to collate and issue the work package. Figure 9 is a sample of the type of chart that depicts this situation. All suppliers to Code 229 are

displayed and discussed every two weeks with senior shipyard managers.

RESULTS OF ZONE TECHNOLOGY IMPLEMENTATION

When comparing the Production Department's performance between two availabilities, it is critical that one compares work of similar scope and size. Figure 10 depicts completed Key Operation (KEOP) performance on several small scheduled availabilities (durations range from about three to twelve months). The KEOP is the lowest level of issued work at the shipyard. Although the ordinate is labelled "Performance Factor," there is, in fact, no factor assigned. The factor that had been assigned in the past was a historical value that the shop normally performed at--less some incentive percentage. For the USS Kidd, USS Hewes, and USS Spruance, there were no such target factors--the shops were expected to perform within the allowed funds.

Figure 10 shows the significant progress that has been made on smaller availabilities. The ordinate represents a percentage of expenditures versus allowed funds for the execution of the work package. The USS Kidd availability, although not a pure Zone Technology ship overhaul, was the first attempt at initiating the Waterfront Management Team concept. It was the shipyard's first attempt (other than the USS Kitty Hawk SLEP) at fundamentally changing the corporate repair strategy. The USS Spruance availability was the first rough attempt at work packaging and executing

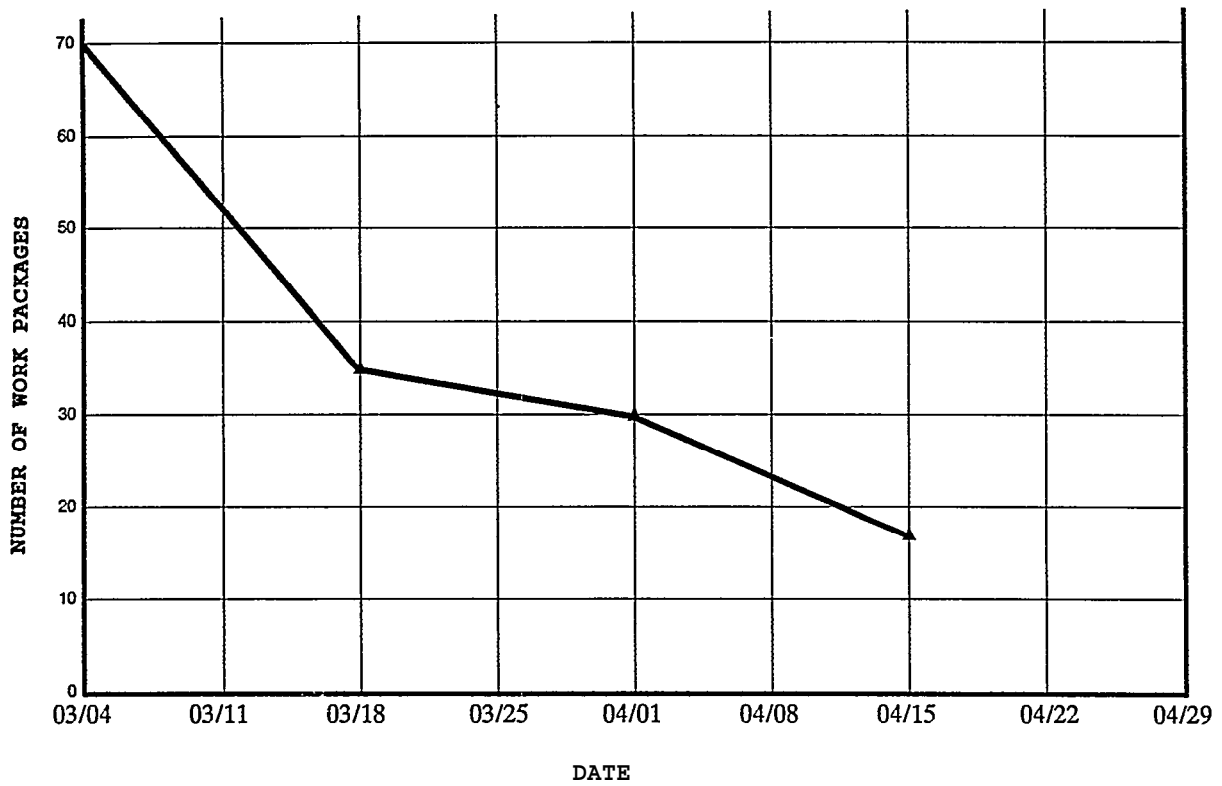


Fig. 9. WORK PACKAGES THAT ARE HELD UP BY A MATERIAL PROBLEM 90 DAYS PRIOR TO THE SCHEDULED START OF WORK

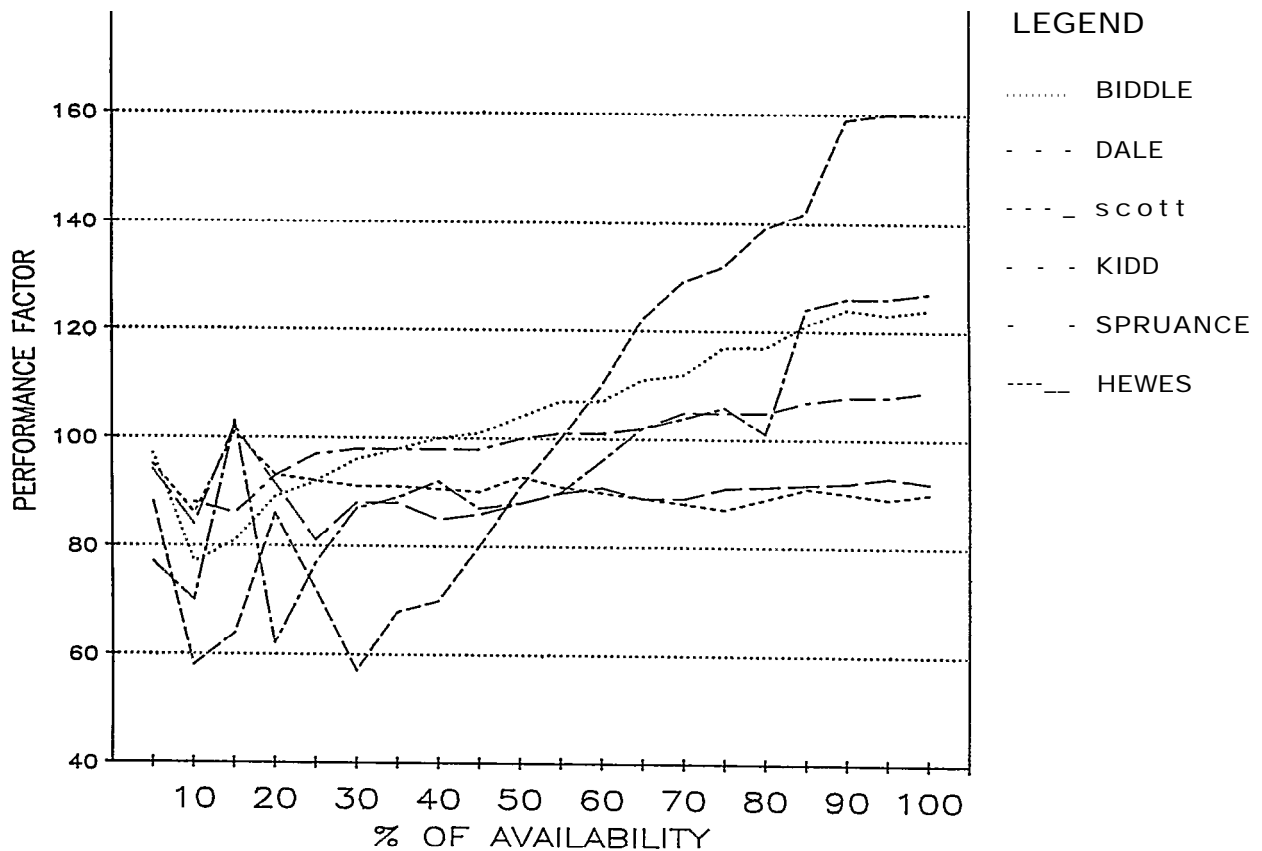


Fig. 10. SMALL AVAILABILITY PERFORMANCE FACTOR

work by geographic area for a smaller availability. The USS Hewes was a 100% planned and executed Zone Technology ship. Although initially there was difficulty in delivering work packages to the Production Department in a timely manner, the fundamental philosophies of Zone Technology were employed.

It is very clear that productivity improvements have been made when compared to the "business as usual" efforts on the USS Scott, USS Dale, and USS Biddle availabilities. Once again, it should be emphasized that these performance indicators have not been "boosted" by any factors so that actual performance would appear to improve: for the earlier availabilities that were actually factored, those factors have been removed from Figure 10. In every comparison mentioned throughout this presentation, estimates of work have not been increased in order to outwardly improve "performance."

The significant productivity improvements that were realized on these smaller availabilities are not easily explained. Simply pointing to "Zone Technology" as the single reason for this

improvement would grossly over-simplify the entire process. The actual reasons for these improvements are as varied and complex as the changes that have taken years to execute. The entire quality process, Integrated Planning and Repair Strategy, Strategic Plan, and Zone Technology played a part in these trends.

Concentrating on a much more complex overhaul, Figure 2 represents completed KEOP performance for all of the SLEP aircraft carriers to date. Figure 2 shows that significant progress in cost improvements are being made for the USS Constellation SLEP. Many managers have claimed that the reason that cost performance is excellent at this point in the availability is that the schedule has slipped significantly--driving the less expensive removal work to the right and delaying the costly installation jobs. This interpretation may have merit and in viewing Figure 11, which displays physical progress versus time, it appears that the USS Constellation SLEP is behind the USS Kitty Hawk SLEP performance.

There is another interpretation of Figure 11, however. Under the concept of Zone Technology, the production schedule

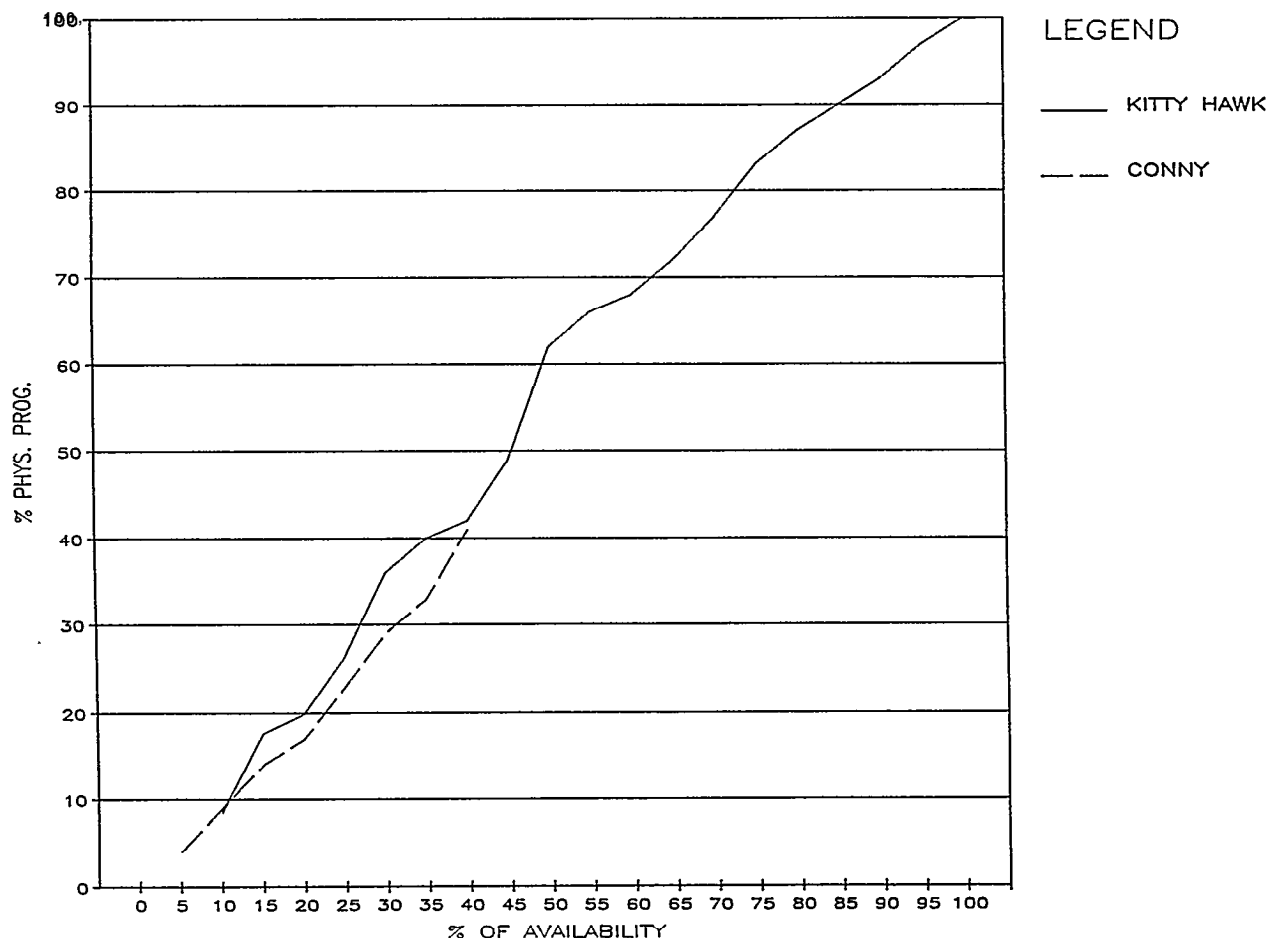


Fig. 11. PHYSICAL PROGRESS VERSUS PERCENT AVAILABILITY FOR CV-63 AND CV-64

drives all other support schedules. The Production Department is issued a work package with a scheduled start and completion date: they are expected to conform to these dates. If the Production Department desires to commence work earlier, the production schedule must be adjusted to the left in order to communicate to the supporting departments that this particular job will require support earlier than originally anticipated. The instrument of this type of communication is legitimate production schedule integrated throughout the shipyard. This policy has been emphasized with absolute firmness from the Shipyard Commander down to the lowest level mechanic. As a result of this philosophy, significantly less work is currently ongoing that is actually scheduled in the future. Compared to every other SLEP, work execution on the USS Constellation SLEP is more closely adhering to schedule.

Notice on Figure 11, that at the 30% time expired point, the USS Kitty Hawk physical progress is about 37%. The USS Constellation physical progress is about 29%. As a shipyard manager, where would you rather be? The natural answer is: ahead of schedule. However when you are executing by phase and area--working ahead of the schedule conflicts with Zone Technology and can (in some cases) guarantee re-work. This is particularly true in the service arena where you should only stage, provide ventilation, and rigging services once for all of the work in an area which requires that particular set up. Trades that start work early in an area disrupt this flow.

In the past, shops would randomly start relatively easy, non-critical work and build up a large cushion of positive schedule variance and physical progress. Huge (unrealistic) gains in schedule were realized on previous SLEP's, only to abruptly lose schedule variance later in the availability. With the advent of the Cost/Schedule Control System, or (CS)², (USS Kitty Hawk SLEP was the first SLEP to be managed with [CS]²) and Zone Technology, the USS Kitty Hawk availability showed a reduction in the number of jobs that were worked in the future. Now, the Production Department working the USS Constellation SLEP has decreased it even more. TWO interpretations: a slow start, or Zone technology at work. It is a combination of both; the overlapping schedule of the two SLEP's prevented, to some degree, the rapidity of manning the USS Constellation. Physical progress, however, now equals time expired and is expected to eventually overtake it as production work is completed to support the undocking later in 1991.

Looking at specific job comparisons between the USS Constellation and the USS

Kitty Hawk SLEP is the next step. Figures 12 through 17 represent the two different types of measurements of SLEP performance utilized for this discussion. Along the abscissa of each graph, the percent of availability is represented from 2% to 30%. This measure normalizes the natural difference in duration of each availability. Since the USS Constellation SLEP is only 127 weeks long as compared to 161 weeks for the USS Kitty Hawk SLEP, this type of normalization is necessary.

Along the ordinate of each chart, either the physical progress or Cost Performance Index is represented. Physical progress for both ships is measured by comparing reported man days of "earned value" in the (CS)² divided by a common predicted end cost for that particular job. For this measurement, the predicted end cost will be represented by a common projected budget for each job. Often the final projected budget at completion for the USS Kitty Hawk SLEP was utilized as a reasonably accurate measure of anticipated growth and re-work. The comparison against a common end cost is necessary to avoid false gains in progress simply due to a lower projected budget at a given time in the availability.

For the other charts, the Cost Performance Index (CPI) is represented along the ordinate and is the expression of the ratio of expenditures and "earned value" or physical progress. To exactly conform to cost requirements, the CPI should be 1.0. CPI's in excess of 1.0 represent a loss on the job and CPI's less than 1.0 represent a gain. Once again, it must be pointed out that "target" factors have been removed from the USS Kitty Hawk SLEP performance figures and were never applied on the USS Constellation SLEP.

In order to achieve a realistic comparison of the USS Constellation and the USS Kitty Hawk SLEP performance, it was decided to choose jobs that were not only authorized on both ships, but ones that met the following criteria:

1. The size of the job must be at least 1000 man days in budget;
2. At least 90% of the job on the USS Kitty Hawk SLEP must have been completed utilizing traditional (non-zone) methods; and
3. The job must be an identical alteration on both ships. If comparing repair jobs then they must be extremely consistent in budget and type of work.

Taking these criteria into consideration, the Arresting Gear Engine (AGE) Ship Alteration (SHIPALT) was

selected. The AGE SHIPALT is nearly identical on both ships, and as such represents an excellent opportunity to compare performance in both schedule and cost. This SHIPALT was almost totally non-zone on the USS Kitty Hawk SLEP and 100% zone on the USS Constellation SLEP. The arresting gear engine alteration is divided into three specific jobs: structural, mechanical, and piping. Since these comparisons will cover the early stages of both availabilities, the piping job will not be discussed since it naturally occurs later in the availability.

It should also be pointed out that any gains in progress that were made during the Pre-SLEP availability (April 12 - July 2 1990) were backed out of these calculations. The USS Constellation SLEP availability formally commenced on 2 July 1990.

Figure 12 shows the AGE SHIPALT (mechanical) production performance in schedule. Since both axes are normalized, it is clear that there were no significant gains made in executing the work.

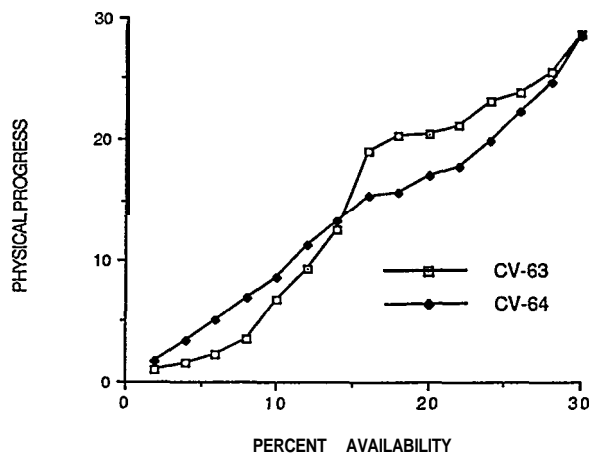


Fig. 12. ARRESTING GEAR ENGINE SHIP ALTERATION (MECHANICAL) PHYSICAL PROGRESS PERFORMANCE

Figure 13 depicts the cost Performance Index (CPI) of the mechanical portion of this SHIPALT. The "spike" in the data for CV-63 is normally attributed to either keypunch or reported progress errors and should be ignored. When the CPI is averaged over the 30 percent time expired, it reveals that the execution of this job has required approximately 16.4% less expenditures of man hours to achieve the same physical progress.

Figure 14 shows the performance differences in the structural portion of the Arresting Gear Engine SHIPALT. In this case, again, no significant schedule improvements have been noted. Figure 15 represents cost performance for this structural job. Averaged over the 30%

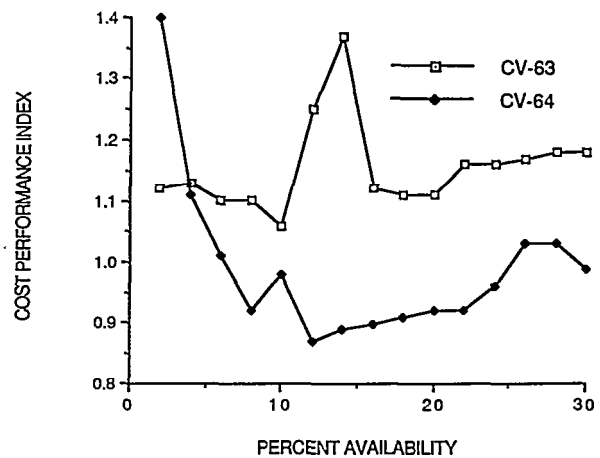


Fig. 13. ARRESTING GEAR ENGINE SHIP ALTERATION (MECHANICAL) COST PERFORMANCE

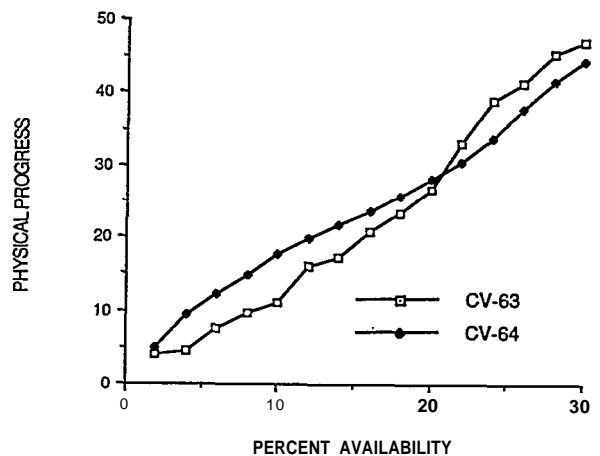


Fig. 14. ARRESTING GEAR ENGINE SHIP ALTERATION (STRUCTURAL) PHYSICAL PROGRESS PERFORMANCE

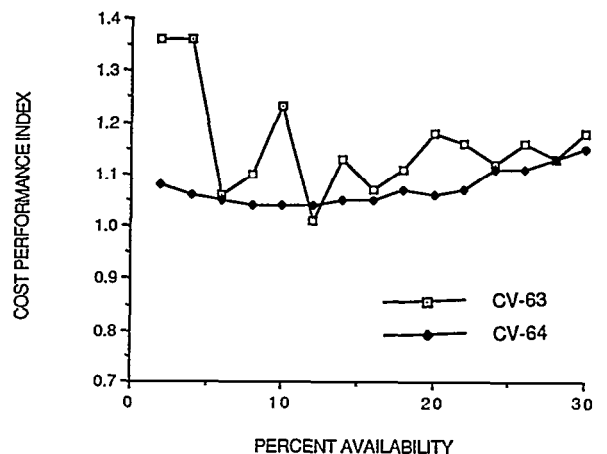


Fig. 15. ARRESTING GEAR ENGINE SHIP ALTERATION (STRUCTURAL) COST PERFORMANCE

time period, the average CPI was 8.1 % lower on the USS Constellation than on the USS Kitty Hawk SLEP. A side benefit of Zone Technology became apparent during

the analysis of the arresting gear structural job. The sudden jumps in the data were not as prevalent for the USS Constellation SLEP as they were for the USS Kitty Hawk SLEP for this particular job. It is believed that this "smooth" work trend may be attributed to several things, but principally:

1. The complete availability of everything production needs to start and complete the work. (This eliminates the cost spikes caused by manning a job and not working it): and
2. Smaller units or "packages" of work.

Smaller work packages enable the first line supervisor to fully understand the work, execute the work expeditiously, and then close the job financially when complete, thus allowing (CS)² data to reflect accurate charges and progress. Senior shipyard managers realize that production supervisors rarely take their "gangs" completely off of the job when work stoppages occur. The Zone Technology solution: Do not issue work to production until the package is fully executable. Work stoppages will still occur, but at a much reduced rate.

The Aircraft Catapult Support System jobs were the only repair jobs selected for comparison. These catapult jobs (all four catapults) have approximately 39,000 man days of work in the total projected budget, and were chosen because of the similarity of work on both ships and the large size of the budget. The large percentage of these jobs are identical--only a small percentage was attributed to actual material condition of each ship's systems.

Figure 16 represents the schedule performance of these particular jobs (combined).

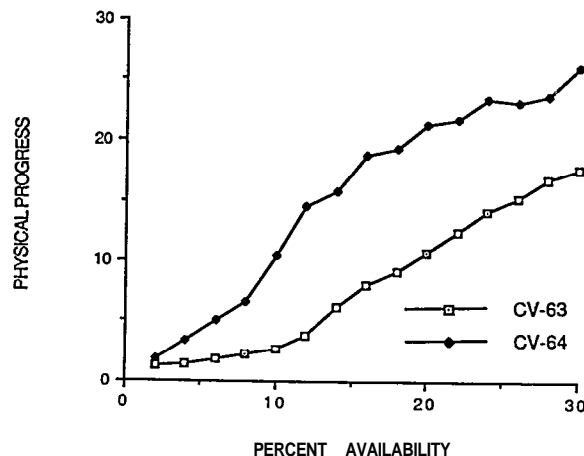


Fig. 16. CATAPULT SUPPORT SYSTEMS (COMBINED) REPAIR PHYSICAL PROGRESS PERFORMANCE

Significant schedule gains have been realized. It should be noted that approximately 7% physical progress was earned during the Tiger Team period--this again was backed out to ensure a realistic comparison. Physical progress was measured toward a common Predicted End Cost of 39,000 man days in order to measure toward a goal which included anticipated growth, new work, and re-work. Even with all of these "limiting" factors, the improvement in schedule adherence is 8.5 %.

Figure 17 represents cost performance on these same jobs. The average cost performance improvement is 17.7 %. When this improved CPI is applied to the increased amount of completed work over time, it equates to an improvement of approximately 1.2 million dollars. This figure represents the amount of money that was not expended to achieve 8.5% increased physical progress on the USS Constellation SLEP up to the 30 percent availability time period when measured against the same period for the USS Kitty Hawk SLEP. Since this is a cumulative performance factor, future over-expenditures, re-work and other factors could possibly reduce this.

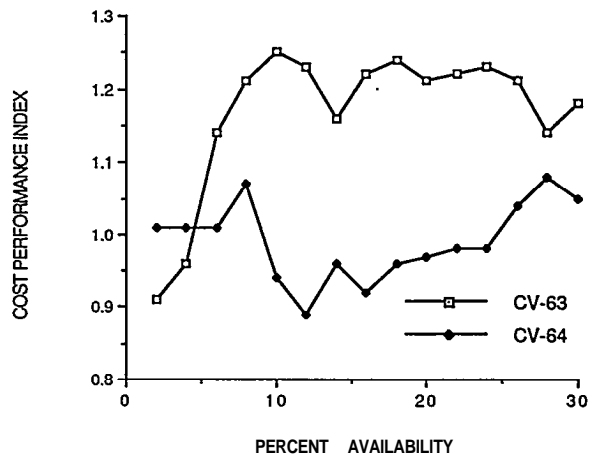


Fig. CATAPULT SUPPORT SYSTEMS (COMBINE) REPAIR COST PERFORMANCE

CONCLUSIONS

Zone Technology is rapidly approaching the point where it is fully institutionalized at Philadelphia Naval Shipyard. Improved planning processes have been permanently implemented and productivity improvements are starting to emerge. Work packaging continues to be refined. The ADP support via the fiber optic local area network gives the shipyard a superior capability over traditional information management and transfer systems. On line database management systems are streamlining the ability to troubleshoot and correct problems before a critical point is reached. Cultural opinions have shifted

and traditional methods of planning and executing work have lost ground and influence. More and more of the Planning and Production Departments are "coming on board" the "Integrated Planning for Production" and "Work by Phase, Trade, and Area" themes. Trends showing significant productivity improvements are positive.

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Information Required From Planning Yards to Support Zone Logic

VIA-2

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ABSTRACT

For over a decade, the use of zone logic, an operational approach consistent with modern manufacturing practices, has become more common in U.S. shipyards. Regarding naval ships, the most significant difference from traditional system-by-system orientation is the application of an implementation strategy even before basic design efforts begin for any combination of ship alterations (ShipAlts). This imposes a unique challenge to each of the approximately thirteen planning yards which are charged by the Naval Sea Systems Command (NavSea) with assessing the costs of, and when authorized developing designs for proposed ShipAlts. The challenge consists of grouping information during the various design stages in a way that makes planning yard design deliverables anticipate the needs of the implementing yards that will employ zone logic. Simultaneously, these deliverables must be suitable for use by eligible bidders who have not yet made the transformation to modern zone orientation. This paper provides guidance for planning yards. The need for them to act as production engineering surrogates until implementing yards are designated, is addressed. Typical planning yard outputs are also described.

INTRODUCTION

The U.S. Navy's Fleet Modernization Program provides for the orderly planning of improvements to ships. Improvement ideas are systematically processed for further study. Dependent on the nature of a proposed improvement investment may be made to "...measure the degree of increase in the ship's capability to perform its mission and..." the estimated "...cost for materials, installation, and design resources needed to carry out the proposed improvement" [1]. Each approved idea becomes a Ship Alteration Proposal (ShipAlt Proposal or SAP), "...a baseline document which

consolidates known technical and materials information...." which is entered into the Navy's Amalgamated Military and Technical Improvement Plan.

Next, each ShipAlt Proposal is usually assigned to a planning yard, specialized by ship class, for preparation of a Ship Alteration Record (ShipAlt Record or SAR). In the process of preparing a ShipAlt Record, a planning yard "...updates and documents the complete technical requirements and specifications that define the alteration. This information forms the basis for ShipAlt installation design efforts and provides data on which ShipAlt programming decisions should be made." This activity is part of Estimating, one of the five major functions for any industrial management cycle (see Figure 1). Estimating is almost always performed by system. The process is the same as that employed by commercial-ship operators when they consult with their own technical staffs, or design subcontractors, during preliminary design activities for ship modernization.

Thereafter ShipAlt programming decisions involve many organizations, budget reviews, adjustments, and/or reassessment of requirements. Methods for implementing each ShipAlt are addressed. This represents the start of Planning. Hereafter, usage of just the word planning implies that design and material definition are included [2].

Ideally, the process leading to a list of approved ShipAlts would include customer/planning yard/implementing yard negotiations aimed at identifying the basic design information that should be used as contract design documents for a specific number of ShipAlts to be implemented simultaneously. The implementing yard's production engineers, as participants in the negotiations, would contribute the most cost-effective implementation strategy, consistent with achieving each ShipAlt's functional objectives, before the major expenditure of design man-hours.

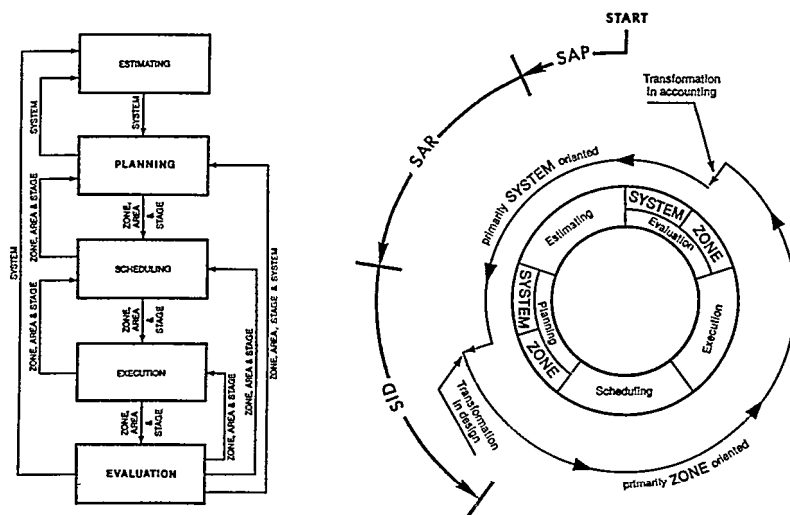


FIGURE 1: Two views of the management cycle for a zone oriented approach to any heavy industrial process, including ship construction, modernization, overhaul, and repair.

The arrangements shown on contract drawings, would then reflect productivity objectives, such as:

- combining foundations, even for different ShipAlt equipment,
- delineating separate outfit packages, regardless of different Shipalts represented, that will be assembled in shops and the sequence for their installation on board,
- maintaining distributive systems in parallel runs that are as straight as possible, regardless of systems represented,
- rip-out, redesign and reinstallation of otherwise unaffected nearby systems when such work would obviously reduce ShipAlt implementation costs, and
- providing sequenced zones per stages by type of work so that work of one type, heavy welding for instance, may be done at the same time for all systems within a zone.

In the absence of such guidance, planning yards insufficiently integrate ShipAlts and have little or no concern for probable overhaul work. Nor do they anticipate the sequence of production activities. They do not usually make transformations from system to zone orientation (see Figure 1), as needed for the more effective zonal approach that has been gaining acceptance in U.S. private shipyards since 1979 and in naval shipyards since 1982 [3,4].

In order to support productivity improvement through zone logic, planning

yards should effect certain changes in the following drawing preparation and material definition areas:

- ShipAlt Installation Drawings (SIDs) - These include drawings for system diagrammatics, key arrangements, temporary access/egress, temporary shoring, rip-out, structure, arrangements, manufacturing, assembly and details, electrical diagrams, and cabling sheets as needed by an implementing yard. SIDs are comprehensive and exclude only the final drawings commensurate with final planning stages which are usually produced by implementing yards. SIDs may include integrated designs to "...represent work required by two or more ShipAlts, usually to be accomplished in the same space or area of the ship...." at the same time. "Completion of SIDs is to be accomplished no later than 12 months before start of scheduled availabilities (A-12)."
- Centrally Provided Material (CPM) - Items first defined in ShipAlt development documents, such as ShipAlt Records, and are designated for central procurement as Government-furnished material. Specific dispositions of CPM are included in Bills of Material (BOMS) that accompany SIDs.
- Locally Provided Material (LPM) - Items that are listed in BOMS that accompany SIDs and that are designated for material management (procurement and control) by implementing yards.

- Long Lead Time Material (LLTM) - This is another way of classifying materials as LLTM applies to both CPM and LPM.

The needed changes require that more production engineering be applied in planning yards before implementing yards are designated.

PALLET CONCEPT AND PALLET LIST

The word pallet has a unique meaning. To designers a specific pallet means the data (design details, material lists, work procedures, test instructions, etc.) needed to produce an envisioned interim product. To material management people the same pallet means the procurement and kitting of the specific materials required. And to production people it means the specific work effort that must be applied to produce that interim product. To production engineers, pallet has all of those meanings. As shown in Figure 2, a pallet serves as an information link which coordinates the efforts of people having different responsibilities, toward a common goal [5].

To palletize means to group information, material, and work as preparation for producing a series of discrete objectives (interim products). A pallet list is identification of the interim products required to complete a project. When a pallet list is presented in the sequence in which the work is expected to be performed, it is the most effective way to express a strategy for ship modernization that should be commonly followed by design, material management and production people. As shown in Figure 3, a production-engineered strategy for simultaneous implementation of any number of ShipAlts can and should be given to ShipAlt designers at least before they start that part of basic design that will become contract design, that is, a negotiated package which first of all does not affect ShipAlt functional requirements, but is consistent with the most productive methods known [6]. Pallet lists describe a production-engineered strategy for coordinating design, material and production management. There is no counterpart to the powerful pallet concept in traditional system-by-system operations.

A strategy for zone/stage orientation is ideal when it is: initially applied in a large-frame sense, subject to constant refinement as more design information becomes available, and dependent more on ship type and nature of work rather than on details of the work to be accomplished. As a consequence, the separation of planning yard designers from implementing yards,

while it still remains a problem, diminishes in significance.

The zone/stage approach requires more and better quality planning in time to guide ShipAlt basic designers. Further, a zone/stage approach requires refinement of the implementation strategy as design progress makes more information available. As shown in Figure 4, starting with basic design, imposition of a strategy or refinement of a strategy always precedes design activity. Refinement continues until just before the final ShipAlt design stage when production engineering input becomes tactical in nature. Detail designers are then advised of the exact way that production needs information grouped on final detail drawings.

Unlike system-by-system design which is usually separate for each ShipAlt and also independent of other design activity, all stages of the design effort for zone/stage orientation are parts of a single process in response to a single strategy regardless of where design work is performed. Thus, information from planning yards to support zone/stage logic should conform to a strategy devised by a production engineering effort even if it is just for basic and functional design stages with the remaining design efforts performed by implementing yards.

DESIGN STAGES

As early as 1986, at least one planning yard which was also the implementing yard, through a special planning effort for modernizing a submarine, combined several "electronic" ShipAlts that required extensive rip out and reinstallation work. Because information was to be grouped by type of work within a zone rather than by system, designers were able to combine foundations for adjacent electronic equipment even though they were for different systems. This made it practical to finish machine foundations in shops and to organize the activities on-board in distinct stages by type of work, including shoring of platforms, ripping out, holding-coat painting, fitting requiring heavy welding, fitting requiring bolting or light welding, electric cable pulling and connecting, and final painting, for all ShipAlts simultaneously.

The overall process, within which design should inescapably be part of planning, may be described as starting with basic design. Basic design involves system-by-system organization of information together with arrangements that are overlaid with a generic, basic implementation strategy. In other words, the information being compiled would be organized as a matrix. When examined

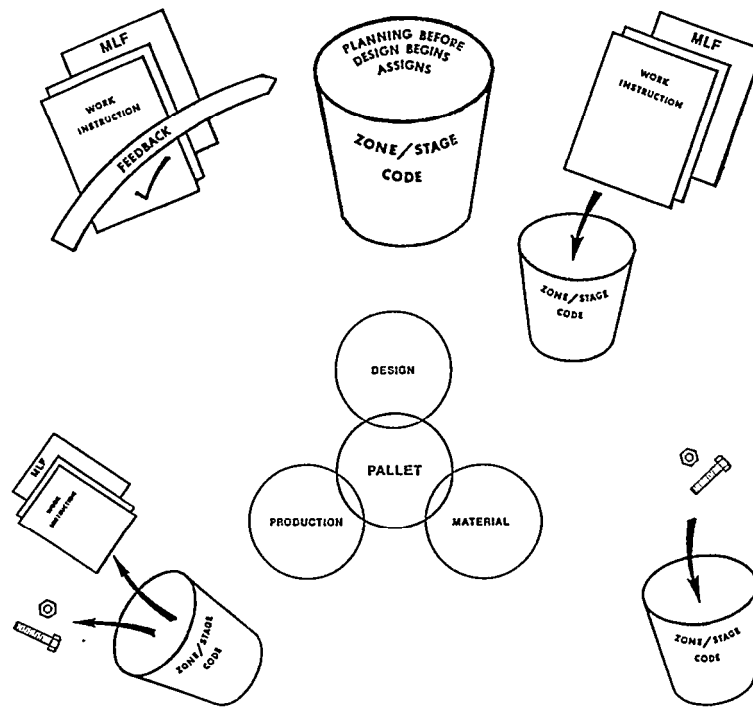


FIGURE 2: The pallet concept applied to ShipAlts.
Pallet = zone/stage = interim product = work package.

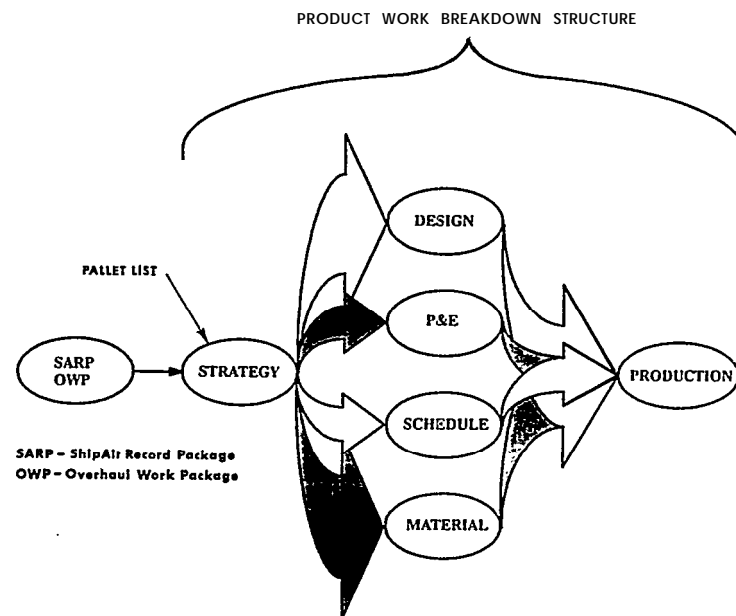


FIGURE 3: The zone approach characterized by strategic planning before design begins. The application of zone logic is greatly facilitated. (Provided by Philadelphia Naval Shipyard)

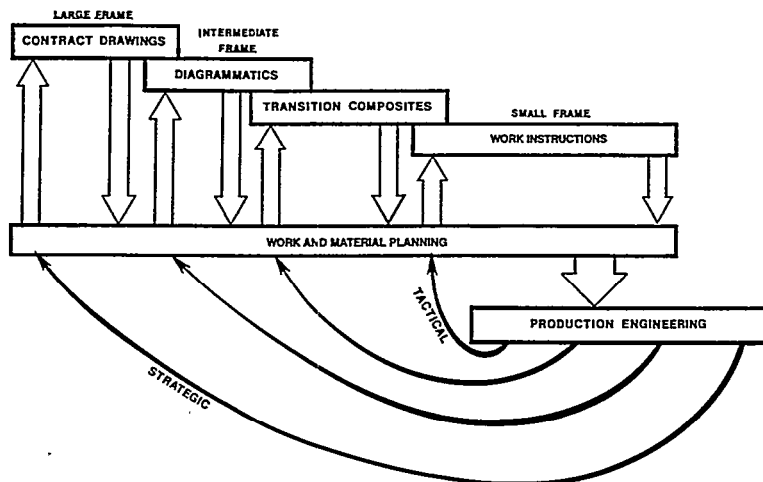


FIGURE 4: For effective ShipAlt implementation, production engineering inputs precede all design stages. Initially, the production engineering input is strategic and, as design progresses, it becomes tactical.

from one aspect, information would be grouped by system. When examined from a second aspect, information would be grouped by zone in a large-frame sense.

The second stage, functional design, should produce quasi-arranged diagrammatics and key drawings by system which fix functional aspects and which represent a degree of refinement of basic design. At the same time the zonal view of the information matrix would reflect a better, but not yet final, implementation strategy. This information grouping is said to be organized in an intermediate-frame sense. Both the first and second planning stages require ShipAlt designers to define all materials required. This means definition by either (a) exact identities and numbers required, (b) exact identities and estimated quantities, and/or (c) identification by material classes and estimated quantities, such as, "so many" lineal feet of medium-diameter electric cable.

Material definition should be refined to an intermediate degree during the second stage. The quasi-arranged diagrammatic should be subdivided by intermediate zones so that the location and receipt date requirements for certain materials may be estimated with enough assurance to initiate their procurement. This emphasis on material definition is extremely important. Many difficult to procure items, valve operators for example for which procurement in a system-by-system approach would be initiated relatively late, can and should be ordered from functional design information. The information is derived from a matrix that simultaneously identifies information grouped by systems and by zones in an intermediate-frame sense,

that is in the context of a now refined generic, basic implementation strategy.

The third stage, transition design, requires the least number of man-hours, and should be implemented by experienced people having simultaneous understanding of ship operational, ship maintenance, and shipyard productivity matters. At this stage all information is "transitioned" to zone orientation. Transition designers establish the final routing of new and/or modified distributive systems per required ShipAlt arrangements and in the context of a finalized modernization strategy. Transition designers establish the rights-of-way for ShipAlt distributive systems, locate the positions of such things as valves and gages relative to machinery, delineate the space reservations required for maintenance, and show interface boundaries that zone-oriented detail designers are to observe. Whether or not subsequent efforts produce maintainable designs is very dependent upon the knowledge and expertise of those who perform transition design. Their outputs, plus the planning yard's file of standard details are all that are needed for effective control of detail design, that is, the final stage which produces information grouped in a small-frame sense. While the transition effects some degree of design refinement, it does not address material refinement.

As a consequence of design being regarded as an aspect of planning, the final or fourth stage, is also referred to as work instruction design. Instructions regarding safety, work procedures, disposition of ripped-out materials, etc., supplement design details and material lists. In some naval shipyards the final design products are referred to as unit work

instructions. They are organized in 8 1/2"x11" booklets that are subdivided so that each segment provides all information required to perform work in a specific zone during a specific stage regardless of different systems [7].

Also, this final stage incorporates the detail requirements for producing pipe pieces and components other than pipe pieces. Thus, the entire planning process starting with basic design is one of constantly subdividing and sorting information [8].

THE PRODUCTION ENGINEERING FUNCTION

Production engineering is most effectively applied as a decentralized pervasive function which has two objectives for each undertaking:

- completion of a project to the customer's satisfaction, and
- manifest improvement in the implementing yard's manufacturing system during execution of the project.

If one of the objectives is achieved without the other a shipyard manager has failed. Both directly impact on the Navy's mobilization potential. Because implementing yards do not have enough understanding of the imperative need for both objectives, they have not, as of 1990, made sufficient pertinent demands on planning yards. Nor have Navy project and program managers, because their missions do not include constant development of manufacturing systems.

Imposition of a production-engineered strategy even as basic design starts and constant refinement of the strategy as subsequent design stages make more information available, is a shipyard manager's way of saying, "I have to protect the methods which enable me to constantly improve the manufacturing system." Thus in a climate of extreme competition, a close association between production engineers and designers, wherever they are located, is essential for a shipyard's survival and for the Navy's ability to get the greatest return from available funds.

Ideally, a production engineering effort requires a few dedicated high-level production engineers from an implementing yard at time of basic design, a larger number of field engineers who are regularly assigned to shops at time of functional design, the same high-level production engineers at time of transition design, and the actual foremen who will supervise the work at time of detail design (see Figure 4). Regardless of their positions, all would understand that their participation in decentralized

production engineering is a regular work responsibility.

While sharing their predecessors' concerns for safety and productivity improvement, foremen, in their production engineering roles, would be primarily concerned with inputting things of a tactical nature, such as, dividing a pallet into smaller work packages and specifying rip-out sequences. Thus, required lead times and work volumes would be greatest for high-level production engineering, would reduce commensurately through the intermediate level, and would be least when foremen provide their inputs (about four to six weeks ahead of scheduled starts for work volumes in the order of forty to 120 man-hours).

In each design stage for a vessel modernization effort, the totality of the project is always discussed but in a different level of detail. For example, during basic design there are relatively few information groups visible from the zone side of the information matrix, each are relatively large, and the information contained is relatively vague. Subsequent design stages increase the number of groups, decrease their sizes, and provide more exacting descriptions of modernization requirements. Information becomes available at an exponential rate. As a consequence, more and more people are required to participate in the production engineering function in order to constantly analyze a developing design and to constantly refine (not change) the strategy.

But in most instances implementing yards are not yet designated when ShipAlt basic design starts. Rather than proceed in a production engineering vacuum, design work should proceed in the context of a basic ship modification strategy that is peculiar to a ship class until an implementing yard is designated. Further, a few qualified production engineers should be employed in each planning yard to act as if they were in a zone-oriented implementing yard until an implementing yard is designated.

Basic ShipAlt designers account for the least expenditure of man-hours, but have the greatest impact on total ship modernization cost. Other designers and material management people account for a greater amount of man-hours and have the next greatest impact. Production people, while accounting for the greatest expenditure of man-hours by a wide margin, have very little impact on total ship modernization cost (see Figure 5). Thus, the key to productivity improvement is in more and better quality ShipAlt planning which will direct design and material management to

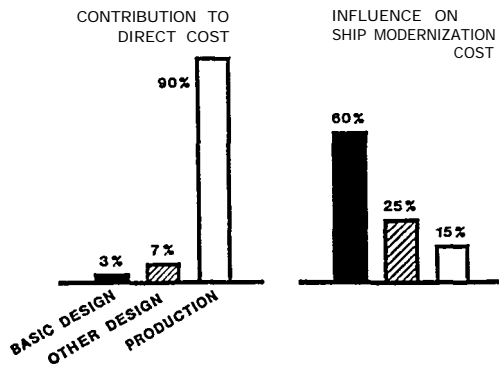


FIGURE 5: A typical comparison of direct cost to its influence on ship modernization cost.

exactly anticipate how production will be implemented. Regardless of the split design responsibilities, it would seem that the manufacturing process for a ShipAlt commences with the start of contract design, that is, all design, material marshalling, and production activities would be in accordance with a single strategy (see Figure 6).

Strategies to the extent that they are described herein, are only intended as models. It is strongly recommended that sufficient funding and high priority should be applied for retaining production engineers who have extensive experience in applying zone logic for shipyard applications. They should work with teams of planning yard designers and prospective production engineers to further develop basic strategies for classes of carriers, submarines, surface combat ships, and auxiliaries [9].

BASIC STRATEGY/SPECIALTIES

The number and nature of required specialties are dependent on ship type and are applied for design just as they are for production. An auxiliary ship may require specialties only for machinery, accommodations, electrical/electronics, and a category sometimes called deck that includes everything else (see Figure 7).

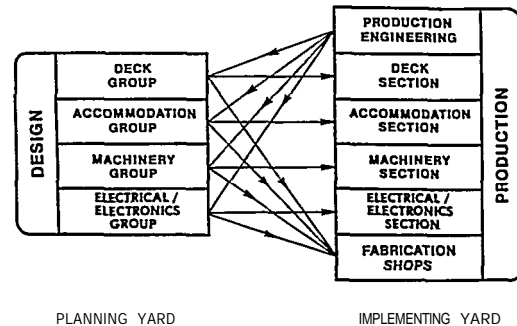
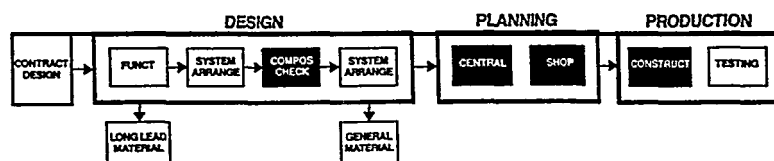


FIGURE 7: Expertise in designing and manufacturing parts and assemblies per problem area is substituted for traditional functional expertise.

Traditional System Orientation



Modern Zone Orientation

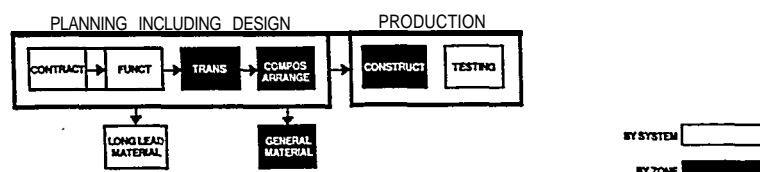


FIGURE 6: Traditional vs. modern manufacturing systems. The former features planning after design. The latter features more and better quality planning before each design stage.

For overhaul and modernization of an aircraft carrier, ten specialties may be employed.

- 0 Services, dock work and miscellaneous.
- 1 All tank work (cleaning, painting, piping, structural, testing), tanks tops, and hull structure.
- 2 All work in main machinery spaces and associated shaft alleys (except tank-top repairs).
- 3 Auxiliary machinery spaces and all associated work (except tank-top repairs).
- 4 All magazine work (except tank-top repairs).
- 5 All pump room work, emergency-generation spaces, air-conditioning spaces, and rudder work.
- 6 Spaces from third deck to main deck (primarily, but not limited to, accommodation spaces).
- 7 Hangar bay.
- 8 Spaces from main deck to flight deck (primarily electrical/electronic spaces) plus island.
- 9 Flight deck.

How they are imposed is illustrated in Figure 8 [9].

The specialties shown only denote basic separation by problem categories, an aspect of Group Technology (GT). Figure 8 also shows that a multiplicity of regions having the same problem category (Specialty 5) are not contiguous to each other nor do they conform with main structural divisions. This is because they represent separation by problem category only.

Geographical representation of a specialty simply designates a sphere of responsibility assigned to a design team and its companion team in production, that have interim product expertise peculiar to a specialty. In some yards the word zone is used in place of specialty. Problem zone or any other term that implies separation by problem category is preferred. The reason for this distinction is to avoid confusion with pallet or zone/stage.

Zone denotes a geographical division and stage refers to a separation in time. Control of work may be achieved by either one, but the most flexible and most effective way to control work is by their usage in combination, zone/stage. If a particular zone is opportune at one point in time, it does not have to be retained if it is not opportune at a different time. For example, structural work on a bulkhead requires a zone that encompasses the bulkhead with sufficient space reserved on each side to facilitate structural work. Later on a zone that is made up of one or more compartments makes better sense for painting work. Such usage of zone/stage for electric cable pulling through all specialty regions is a better and more complex example [10].

Obviously zone/stage work packages often have to straddle the boundaries between specialties. In each such case, the different specialists have to coordinate their planning with each other. Packaging work by zone/stage per specialty is means to assure that different work teams are not unintentionally in the same zone at the same time. There is no counterpart planning technique in system-by-system operations. Therein, workers have to compete for access to on-board work, because the planning performed for them is incomplete.

Also, zone-oriented production engineers are able to advise designers of a manufacturing system's most effective work flows. From the beginning and through continuous interaction with designers, their objectives include getting as many zone/stage work packages into preferred problem areas. That is, as much as possible work is performed in rationalized work flows. Job shop work is minimized.

As prerequisites for effective implementation of zone logic, the specialty regions and planned zone/stage/problem area classifications of work have to be considered even for the earliest required ShipAlt Installation Drawings (SIDs) and their attendant bills of material (BOMS).

LARGE-FRAME PLANNING

Each specialty in design and its production engineering counterpart, basically proceeds as if the region for which it is responsible is a separate ship. Of course there must be coordination with other specialists at numerous interfaces, some of which can be very significant.

With only the earliest available information, such as Ship Alteration Proposals (ShipAlt Proposals or SAPs),

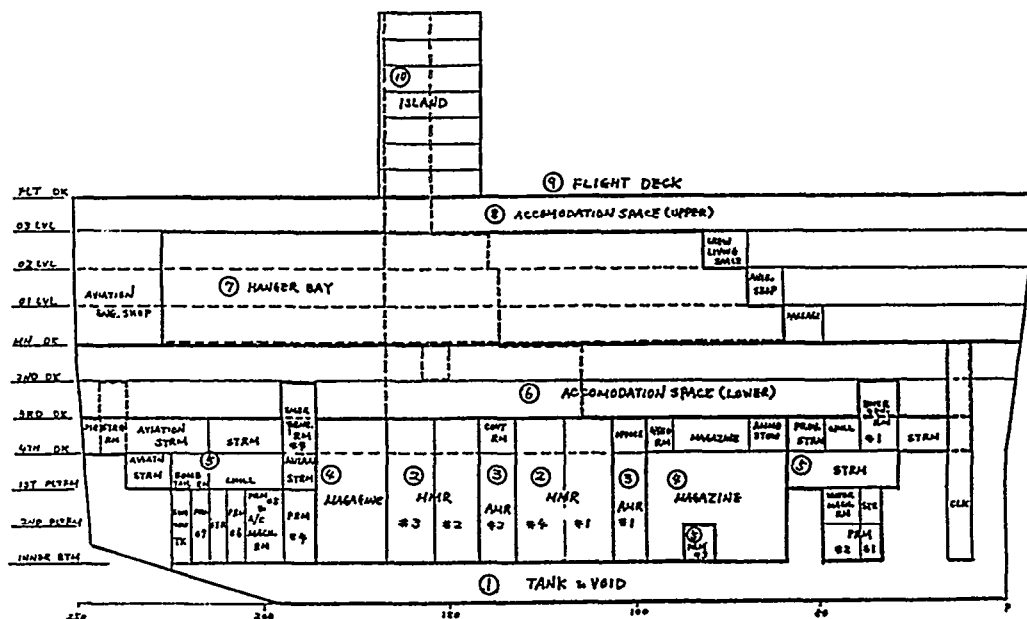


FIGURE 8: Specialties employed for modernization of an aircraft carrier. (Provided by Philadelphia Naval Shipyard)

TABLE I: Generic pallet list for an electronic space

Complete Space	1	Tagging equipment and fittings with disposition instructions.
Complete Space	2	Disconnecting electric cables.
Lower only	3	Removing equipment and fittings that do not require extensive gas cutting.
Lower only	4	Removing electric cable.
Lower only	5	Removing fittings, including foundations, that require extensive gas cutting.
Complete Space	6	Removing insulation.
Upper Only	7	Removing electric cables.
Upper Only	8	Removing fittings that do not require extensive gas cutting.
Upper Only	9	Removing fittings, including foundations, that require extensive gas cutting.
Complete Space	10	Clean and prime.
Upper Only	11	Fitting by heavy welding.
Lower Only	12	Fitting by heavy welding.
Complete Space	13	Touch-up followed by 1st-coat painting.
Upper only	14	Fitting by light welding and bolting.
Lower Only	15	Fitting by light welding and bolting.
Complete Space	16	Touch-up followed by remaining painting.
Complete Space	17	Equipment tests.

and knowledge of a ship class, production engineers/specialty are able to negotiate with customers and designers in order to create a mutually acceptable pallet list (strategy). This is not particularly difficult for specialists because they only have to express a strategy in terms of zone/stage/problem area designations. Specialty Number 1 for tanks and voids, as shown in Figure 8, provides the simplest example. Zone/stage/area work packages could be sequenced by the specialists to start aft and go forward as a single work flow or, production manpower permitting, as two flows progressing side by side. Also, each zone could address a single tank or a group of adjacent tanks dependent upon the degree of control desired.

For tank cleaning, scaffolding and temporary service installations, holding-coat painting, inspection, and the rip out of fittings, it makes sense for zones to coincide with boundaries formed by structure. For rip out and replacement of structure, zones that encompass the structural boundaries are required. Thereafter, zones that are made up of single tanks or groups of tanks should again be employed for installing fittings and for painting. The clever composition of a zone/stage list insures, for example, that a team dismantling fittings on one side of a bulkhead is not endangered or disrupted by people assigned to make cuts through the bulkhead from its other side.

The sequence for work is organized like a series of rolling waves, wherein the crest of each represents a category of work (problem area). Thus the team assigned to tank cleaning leads, followed in succession by other teams with zone/stage control assuring that no two teams are unintentionally in the same zone during the same stage.

Another example which pertains to extensive modernization of an electronic space could employ two zones that are separated by a horizontal parting plane at about midway between the deck and the overhead, that is, upper and lower zones. A generic pallet list for such spaces is illustrated in Table I. This pallet list should be thought of as a series of empty buckets of varying sizes, that have yet to be filled with the detail design information, materials, and skills needed for realizing a series of different interim products (see Figure 2).

The earliest produced SIDs, such as General and Machinery Arrangements, should incorporate identification of the specialties that will be involved, the extent of their involvement, the boundary areas that require special coordination by two or more specialties,

and the basic, often generic, pallet definitions. In addition to the locations for major equipment, lists of all material required should also be grouped to match the specialties, but only as (a) exact identities and required numbers, (b) exact identities and estimated quantities, and/or (c) identification only by material classes and estimated quantities. This material compilation, broken down by specialties and the corporate history of man-hour/material relationships comprise a solid framework for the largest frame budgets and schedules. Planning that is consistent with zone logic vastly improves the quality of information in ShipAlt Record packages before they are sent to cognizant approval authorities.

The process for ordering major items that are classed as both Centrally Provided Material (CPM) and Long Lead Time Material (LLTM), with information thus far available, is not different from that traditionally employed.

The first of the SIDs produced, such as general arrangements, in addition to reflecting commitment to meet customer requirements, contain the strategy framework achieved by production engineer/designer interaction. The framework is susceptible to refinement but not to change per se. Thus, the SIDs which are the equivalent of contract drawings in the commercial world, should document production's commitment to a strategy before the major expenditure of design man-hours.

Actually, the zone logic planning thus far regarded as large-frame planning, leapfrogs ahead into small-frame planning when the specialists provide previews, their pallet lists. These however, are the empty buckets, identified by title and code, which are still unrefined and which have yet to be filled with the detail design information, materials, and skills needed for realizing a series of different interim products.

INTERMEDIATE-FRAME PLANNING

Intermediate-frame planning, in addition to functional design, is chiefly concerned with production and material control matters. It provides good enough estimates of certain materials, other than CPM or LLTM, for which special control and release of purchase orders before detail design starts, are extremely beneficial.

Approval authorities would further benefit because functional drawings are required to be more sophisticated than those traditionally prepared. All aspects that affect safety and operations are included (in the commercial world that includes virtually

everything for U.S. Coast Guard and American Bureau of Shipping approvals). The objective is to minimize, if not eliminate, the need to submit drawings for approval after relatively intensive detail design efforts begin. Further, designers are required to quasi-arrange diagrammatics.

Each Material List per System (MLS) still addresses all materials required for a system. But because more information is generated during functional design, a MLS reflects considerable refinement. The identities and quantities of more material items are exactly known. Thus, a MLS, while not yet exact, contains fewer identifications by just material classes and fewer estimates of quantities required.

The most advanced application of zone logic features a computer program to compare materials as they are being defined in the intermediate-frame planning stage to those which were identified during the earlier large-frame planning stage. The program sorts and collates in order to answer two questions:

- 1) Are any materials now being defined for the first time? and
- 2) If not, do quantities now being defined exceed those in the material budget developed as part of contract design?

Newly identified and/or revised quantities of materials are immediately addressed by material managers for their procurement significance. But more important, because of the material/man-hour relationships derived from corporate history, approval authorities and others concerned with production control, before an implementing yard is designated, are simultaneously being warned by the computer that man-hour budgets should be adjusted and schedules should be confirmed or changed accordingly. The terms material volume and work volume are synonymous.

Another profound improvement in the content of ShipAlt Records results from production engineers per specialty having to divide the regions for which they are responsible into a reasonable number of intermediate zones (in warships perhaps as few as five and as many as fifteen for each specialty). Further, production engineers are required to sequence the intermediate zones consistent with how they plan the progression of work.

The boundaries of intermediate zones and their sequencing do not have to exactly encompass a group of zones/stages defined in previously

conceived pallet lists, because intermediate zones/stages are only used to get better estimates of material and

work volumes as needed for:

- man-hour budgeting and scheduling in an intermediate-frame sense, and
- issuing purchase orders for certain materials, which specify just-in-time deliveries in relatively small lots, immediately upon designation of an implementing yard, that is, without having to wait for material lists which accompany later prepared detail design drawings.

As means to achieve these objectives, functional designers should overlay their quasi-arranged diagrammatics on the defined intermediate zones. The overlays then show what portions of various systems are likely to appear in each intermediate zone. Functional designers should also make corresponding divisions in each MLS.

The latter action sets the stage for release of initial purchase orders that specify just-in-time deliveries for certain materials, before detail design starts. Thus, the name Material Ordering Zone (MOZ) is used in place of Intermediate Zone. Material procurement gets a tremendous jump start.

Intermediate-frame planning, of course, encompasses the preparation of functional drawings. At the same time, with no less priority, it too leapfrogs ahead with its strong emphasis on accelerating definition of materials, and when necessary even initiating their procurement. The material information is grouped for just-in-time deliveries in an intermediate-frame sense, and simultaneously, in a way that facilitates later subdivision by detail designers for just-in-time deliveries in a small-frame sense.

TRANSITION PLANNING

Transition planning is unique to zone logic. Some regard it as the beginning of detail design efforts, but its importance justifies treatment as a distinctly separate function. Transition planning is the last opportunity to nail down significant operational, maintainability, and productivity features. Further, the completion of transition planning is a natural juncture for the transfer of planning responsibilities from a planning yard to an implementing yard,

Again, specialists match problem categories. Fortunately the transition

stage requires the least expenditure of man-hours, but because of the breadth of knowledge required, the best available people should be employed. In the context of specialties, transition planners have to understand ship operational and maintenance matters and prospective implementing yards' manufacturing systems.

Transition experts use as their primary inputs, contract arrangement drawings, diagrammatics, and pallet lists. They:

- overlay distributive system diagrammatics on contract arrangements in order to show system paths and their relationships to each other,
- designate foundations that should be combined and/or integrated with hull structure, regardless of systems,
- designate the approximate positions of controls, valves, gages, light fixtures, ventilation outlets, etc., not already fixed on contract drawings, relative to important equipment and machinery so as to enhance their operation,
- designate space reservations for maintenance and routes for initial installation of machinery and equipment as well as for their removal and reinstallation during future overhauls,
- designate requirements for extraordinary shoring, scaffolding, and temporary services,
- refine and superimpose the pallet list (zones/areas/stages) geographically and by coding on the planning yard's design model, and
- designate contingent pallets for CFM and LLTM that could cause significant disruption if delivery dates are missed.

In other words, transition planners per specialty create mechanisms for immediate control of detail design in order to insure operability, maintainability, and productivity, without themselves being involved in detail design. As planning yard transition documents should be incorporated in ShipAlt Records together with standard design details, they are powerful means for approval authorities to control detail design development by implementing yards and/or subcontractors.

The refined pallet lists, as superimposed on a design model, are for use by implementing yards to assign detail design responsibilities by zone/stage, regardless of systems represented, and to identify interfaces between pallets.

Transition planners should have little need to request approval to deviate from general and machinery arrangements, because they would probably be the same individuals who provided production engineering input during the large-frame planning stage. Their thinking, introduced during customer/planning yard negotiations a short time before, should already be in the arrangements mandated by ShipAlt Records. The changes, really adjustments, they might propose during transition planning would for the most part be of limited scope and as consequences of functional drawing and MLS developments.

With Computer Aided Design (CAD) there is some risk that designers will continue to use the developing design model without pausing to record the end of the transition stage. That is, they could further manipulate what is in the computer for further design development without making a record of what transition planners imposed. Having access to the transition planning afterwards is obviously important for discussions that could come up during and following detail design. Having files of transition planning from past modernization efforts, is also important because they could be applied to future projects by adaptation and because they are needed for teaching transition planning.

SMALL-FRAME PLANNING

Planning yard people should understand the final planning stage that normally would be assigned to an implementing yard. The entire effort, from the start of large-frame planning to the delivery of a modernized ship, has to be regarded as part of a single manufacturing system in which design is a true aspect of planning. Production engineers and designers at all levels, in both planning yards and implementing yards, should be the recipients of feedback from completed work packages. All are obligated to analyze results. Analysis is greatly facilitated when cost/schedule returns are per types of interim products, that is, per rationalized work flows.

Proposed changes in work methods or design details that may benefit a particular stage in a particular work flow, also have to be evaluated for their impact on the entire manufacturing system. Each planning yard functionary, therefore, should understand the entire

process at least within the context of an assigned specialty.

Also, the transfer of responsibilities from a planning yard to an implementing yard at the end of a transition stage is not always practical nor, in some instances, desirable. For example, if the proper operation of a complex weapons control space is very dependent on the exact locations of all equipment and fittings, the planning yard may have to perform detail design as a customer imposed condition even before an implementing yard is designated.

Transfers of planning responsibilities do not have to be made at the same time for each specialty, nor even for different groups of ShipAlts within a specialty. What should be transferred and when it is transferred should be the consequence of customer/planning yard/implementing yard negotiations. Additional factors to be considered include time remaining before a ship availability starts, unique expertise, and the planning (including design) workloads in both the planning yard and in the designated implementing yard. Regardless of how the remaining planning activity is assigned, that which is transferred and when it is transferred should be the consequence of a formal transfer meeting and a written transfer agreement.

Thus, for ideal grouping of information to support zone logic, planning yard people have to understand the application of a PWBS for a manufacturing process, starting with review of the Ship Alteration and Repair List (SARP), or such other authorizing document, through test and operation (sea trials). A typical PWBS, modeled to include rip-out and installation of fittings, is shown in Figure 9. Planning yard people would have to also understand how the same logic is employed for structural and painting work in order to plan for integrated structural, fitting, and painting work [5,11].

Planning yard production engineers, until relieved by implementing yard production engineers, should lead designers in a process that may be characterized as continually assessing, refining, and regrouping available information. The process should progress, as a baton passed in a relay race, when implementing yard production engineers and designers take over until the information is sufficient and its grouping is ideal, for rationalized work flows.

A tremendous advantage that stems from specialization, is that the degree of detailed information and the way it is grouped does not have to be the same for

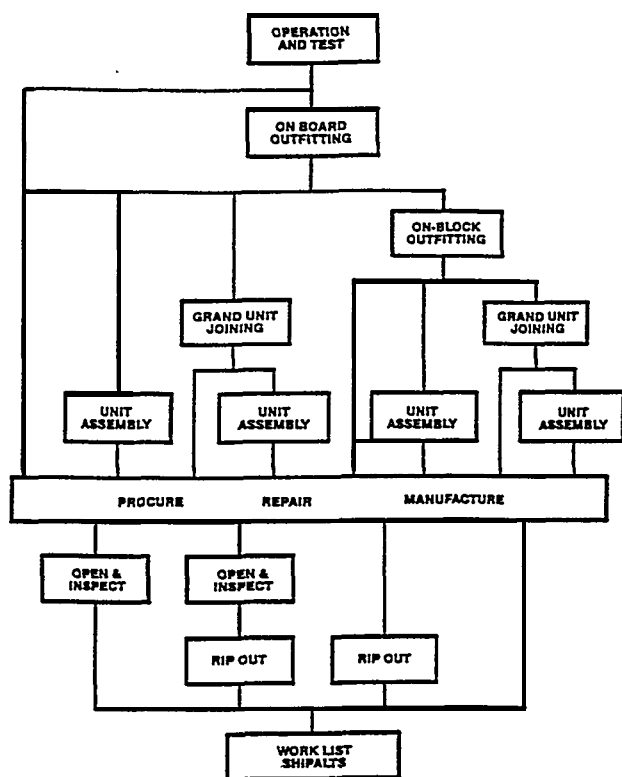
each specialty. A zone technology work package for complex electrical and electronics work to be accomplished in a specific zone during a specific stage, or even in a series of stages, may consist of an 8 1/2" by 11" booklet made up of a cover sheet and a number of distinct sections as shown in Figure 10. In contrast, a work package for piping renewals for all systems in a group of contiguous tanks, can consist of one composite drawing that is overlaid and coded for zone/stage/area control. The composite would also feature a material list that is divided to match the planned implementation of work [7].

Regardless of whether booklets or composites alone are used, all systems, including tubing, should be included. Exceptions should be limited to short runs of lighting circuit cable and short lengths of tubing in the vicinities of gages. Allowing systems to be field run is the same as giving away control.

Initially, booklets like that described in Figure 10 are sometimes justified only until workers who, in the past were required to apply only their craft expertise, have developed expertise per product. How to simplify work instructions without losing control should be continuously analyzed following implementation of work.

Even ShipAlt work in a space that is moderately complex and requiring CPM and/or LLTM, could be controlled by a single composite drawing having overlaid zones accompanied by codes that identify stages and problem areas. The material list could be conventionally prepared but would have to be supplemented by two columns. One would identify the pallet destination(s) for each line of material (instructions for material marshalling people). The second would identify contingent pallets for CPM and/or LLTM. This latter requirement is very important.

In effect, contingent pallets are warnings to the customer, planning yard, and implementing yard people concerned with events leading to material palletizing. Because productivity indicators are different for something that could have been fitted in a shop assembled unit or landed in a relatively accessible space on board, as compared to later landing the same item in what has become a relatively inaccessible space on board, the required increase in the man-hour budget and the shift in the man-hour distribution due to late delivery is known beforehand. In other words the impact on productivity and schedules are preassessed, mostly analytically determined in the absence of emotional argument, and very clear.



PLANT LEVEL	FW LEVEL
1	9
2	8
3	7
4	6
5	5
6	4
7	3
8	2
9	1

PRODUCT ASPECTS									
ZONE	PROBLEM AREA				STAGE				
SHIP	MACHINERY	DECK	ACCOMMODATION	ELECTRICAL/ELECTRONICS	OPERATION AND TEST				
ONBOARD DIVISION	NIL	SIMILAR WORK IN SMALL VOLS/ SPECIALTY	SIMILAR WORK IN LARGE VOLS/ SPECIALTY	SIMILAR HIGH SKILL WORK/ SPECIALTY	RELAYING	NIL	WELDING	NIL	RELAYING
					RELAYING	NIL	WELDING	NIL	RELAYING
BLOCK	NIL	COMPONENTS IN A LARGE QUANTITY/ SPECIALTY	COMPONENTS IN A SMALL QUANTITY/ SPECIALTY	NIL	RELAYING	NIL	WELDING	NIL	RELAYING
					RELAYING	NIL	WELDING	NIL	RELAYING
UNIT	NIL	LARGE SIZE UNIT	SMALL SIZE UNIT	NIL	WELDING	NIL	JOINING	NIL	WELDING
					WELDING	NIL	JOINING	NIL	WELDING
COMPONENT	NIL	SCULPTING	OVERHAULING	IN-HOUSE MANUFACTURE	CUTTING	MANUFACTURE	PALLETTING	MANU.	NIL
ONBOARD DIVISION	VIDEO	VIDEO	VIDEO	VIDEO	REFINE PLANNING	INSPECT AND REPORT	DISASSEMBLY	DISASSEMBLY	DISASSEMBLY
ONBOARD DIVISION	VIDEO	VIDEO	VIDEO	VIDEO	REFINE PLANNING	INSPECT AND REPORT	DISASSEMBLY	DISASSEMBLY	DISASSEMBLY
SHIP	MACHINERY	DECK	ACCOMMODATION	ELECTRICAL/ELECTRONICS	PLANNING (INCLUDES DESIGN)	PRE-ARR. IMP.	OVERHAUL WORK LIST	SHIPALTS	SHIPALTS

FIGURE 9a: Typical work flows by problem area for ship modernization.

FIGURE 9b: Typical manufacturing levels and product aspects for ship modernization.

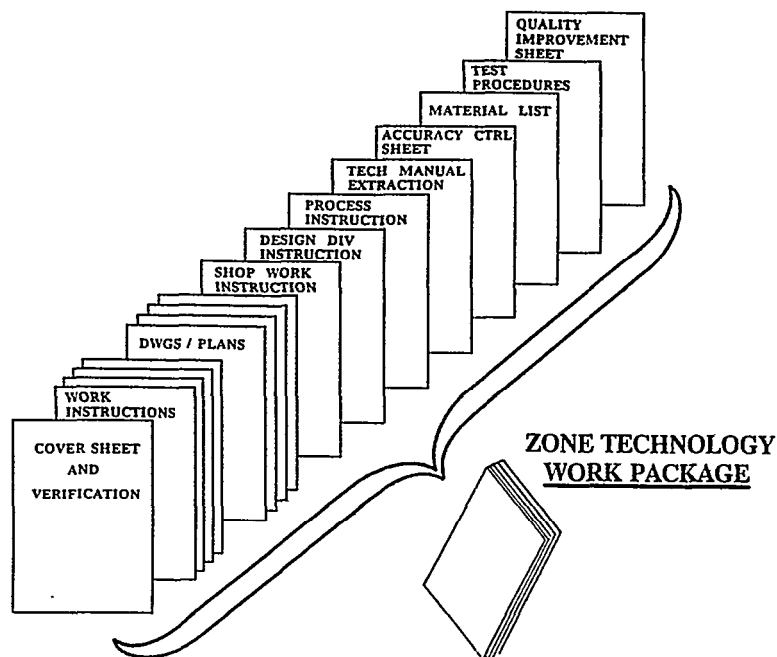


FIGURE 10: A work instruction booklet could incorporate a number of pallets. (Provided by Philadelphia Naval Shipyard)

Some people who are responsible for timely delivery of CFM are not likely to be enthused about the contingent pallet concept "because it gives claims advantage to implementing yards." They should be made to understand that all material procurement matters, no matter how remote or when initiated, become a de facto part of an implementing yard's manufacturing system. The use of rationalized work flows also facilitates effective analysis of problems and the extent of their impacts. Regardless of who is responsible, the Navy's best interest is always served when the impacts of late materials are accurately identified and assessed. Otherwise, attempts to improve material support activities will be futile.

Detail designers also have to be given production engineering guidance about what different fittings impose the same type of work so that they may be incorporated on the zone/stage composite regardless of systems represented. An example of work that should be included on the same composite is shown below. Each dash or heading if there are no dashes would represent an individual composite. Similar lists should be prepared separately for each specialty.

Tagging

- All electrical/electronic equipment, furniture, pipe, ventilation duct, lightweight foundations to be removed.
- All heavy foundations, stanchions, beneath deck stiffeners to be removed.
- All electric cable to be removed.

Removing Small Fittings

- Generally everything limited by weight and length that one worker can remove safely (includes electrical/electronic equipment, furniture, pipe, ventilation duct, and lightweight foundations).
- Electric cable.

Installing Shoring & Scaffolding

Removing Large Fittings

- Generally everything for which more than one worker is required for safe removal (includes electrical/electronic equipment, furniture, large diameter pipe, ventilation duct of extraordinary length, heavy foundations and beneath deck stiffeners).

Cleaning & Holding-Coat (primer) Painting

Laying Out Reference Lines and Points (for all systems)

Fitting Large Components

- Generally everything for which more than one worker is required for safe installation (includes electrical/electronic equipment, large diameter pipe, ventilation duct of extraordinary length, heavy weight foundations and beneath deck stiffeners).

Inspecting (for compliance with dimensional tolerances and weld quality).

Removing Shoring & Scaffolding

Installing Small Fittings (small diameter pipe, ventilation ducts, electric cable lengths, etc.)

Connecting Electric Cable Ends

Testing (initial phase)

Painting (all but finish coat)

Testing (final phase)

Cleaning, Painting (final coat) & Labeling

How the fittings are grouped should be based upon the equivalence of work. They should not be grouped to reflect how production shops are organized unless the shops themselves are product oriented. Often, the separations are influenced by work volume, access to work, skills available, and materials available. The grouping of information to facilitate productivity should be used as the basis for developing product trades, individuals or teams having all skills necessary to produce a class of interim products regardless of the systems represented. In other words, people should be grouped to match a PWBS [9,12].

The process of data reduction which started during large-frame planning and which is thus far described through pallet definition, is still not complete. In traditional organizations what remains, the detail planning for pipe pieces and components other than pipe pieces, is regarded as part of production. Detailing for the manufacture of pipe pieces in pipe shops and mold loft operations for structural work, are examples. Regardless of where performed, what should be understood in planning yards as well as in implementing yards is that such activities are a continuation of the planning process shown in Figure 4.

Zone logic, which uniquely provides for systematic data reduction from large-frame to small-frame focus, also identifies arbitrary restraints that prevent the full exploitation of cAD

facilities. For example, the planning process can easily continue in a planning yard until it produces the data, such as, sketches, tables, printouts, material lists, and even NC code required for manufacturing components such as pipe pieces, ventilation duct sections, pre-cut electric cable lengths, distributive system supports, foundations, ladders, and walkway sections.

If CAD systems are generally available and compatible, the planning yard produced design model can be readily transferred to an implementing yard after any planning stage. Similarly, because CAD terminals can be made available in shops, a yard planning department can readily defer the detailing of components, or even the preparation of some zone/stage work packages, to yard shops. With the same ease, a yard planning department can assign such work to qualified subcontractors.

Since only completed components, including those to be overhauled or modified, appear as line items in MLFs and the materials from which they are assembled appear in MLPs and MLCs, the MLF/MLP and MLF/MLC relationships are those of structured material lists. MLP and MLC represent the last division of information in the planning process.

As envisioned by planning yard production engineers at the very start! work associated with each MLP and MLC is a pallet which also has zone/stage/area classifications. But, as long as pallet completion dates are met, a shop manager working only with problem area classifications, can fully exploit GT for internal shop operations independent of how GT is exploited elsewhere. This permits just-in-time batch fabrication or overhaul of different components, of varying designs required in different quantities, on rationalized work flows.

THE BENEFITS OF COMBINING SHIPALTS: A SPREAD SHEET APPLICATION

The identification of potential ShipAlts to be accomplished for a given availability is an iterative process. Often there can be considerable change in both the number and type of ShipAlts that are addressed from the earliest planning stages until the final work scope is chosen. Additionally, this uncertainty makes the development of meaningful cost estimates for various combinations of ShipAlts difficult to obtain. Consequently, a simple tool to monitor and help evaluate numerous combinations would be useful, both for Planning Yards throughout the planning process and for Navy decision-makers, as they consider cost and operability tradeoffs.

The development of a generic overhaul strategy for ship types has been described previously. In effect, this strategy provides a list of zone/stage pallets by specialty. In the context of this available generic strategy, ShipAlt designers can identify pallets impacted by potential ShipAlts very early in the planning process. In fact, one of the first tasks of the planning yard should be to identify these pallets associated with each ShipAlt. Once this has been accomplished, the information can be input to a spreadsheet matrix, which has the pallet list that forms the generic strategy on one axis, and the ShipAlts under consideration on the other axis, as shown in Table II. The four specialties employed in this example are the likely ones for a naval auxiliary, including machinery (M), deck (D), accommodations (A) and electrical/electronics (E/E). The row headings show there are three different ShipAlts under consideration. Thus, as multiple ShipAlts are considered and entered into the spreadsheet, a record of the pallets required is developed, and the potential synergistic benefit of performing combinations of two or more ShipAlts is identified and computed.

After each ShipAlt has been analyzed only in enough detail to identify pallets required, data can be entered into the spreadsheet. A "1" input into the cell for a specific pallet and a specific ShipAlt indicates that a pallet is required to complete the ShipAlt. Cells for pallets not impacted by the ShipAlt have "0" entered. As additional ShipAlts are identified and the estimating process begun, data are input to the spreadsheet for additional columns reflecting the pallets impacted by these additional ShipAlts. Table III shows the spread sheet with initial data (for three fictional ShipAlts) input. Note that the initial planning and design analysis is only to identify pallets by specialty involved in each ShipAlt. At any point in this process, the spreadsheet matrix can be screened to identify pallets that are impacted by more than one ShipAlt. This first output matrix is shown in Table IV. In the column labeled zone/stage multiple impacts in this matrix, a "1" appears in each cell in which more than one ShipAlt has an impact and a "0" in each cell in which one or no ShipAlt has an impact. Pallets having the potential for time or cost savings are thus clearly identified.

As the ShipAlt designers make more information available, estimates of work content (cost) per pallet, perhaps by estimating parametric material weight and multiplying by the appropriate productivity index, are obtained. This data can then be entered into

TABLE II: Initial spreadsheet input matrix

ZONE	STAGE	SAR1	SAR2	SAR3
M1	1			
	2			
M2				
	1			
	3			
M3	1			
	2			
	3			
M4	1			
	2			
M5	1			
	2			
M6	1			
	2			
M1	1			
M8	1			
	2			
M9				
	1			
M10	1			
	2			
Total =				

ZONE	STAGE	SAR1	SAR 2	SAR3
D1	1			
	2			
D2	1			
D3	2			
D4	1			
D5	1			
	2			
Total =				

ZONE	STAGE	SAR1	SAR 2	SAR 3
A1	1			
	2			
A2	1			
	2			
	3			
A3	1			
	2			
A4	3			
	2			
A5	1			
A6	1			
	2			
Total =				

ZONE	STAGE	SAR1	SAR 2	SAR3
E/E1	1			
	3			
E/E2	1			
	2			
E/E3	3			
	2			
E/E4	1			
E/E5	1			
E/E6	1			
	2			
	4			
E/E7	1			
	2			
	3			
Total =				

TABLE III: Initial spreadsheet data input

ZONE	STAGE	SAR1	SAR2	SAR 3
		1	1	1
M1	1	1	1	1
		1	0	1
M2	2	0	1	1
		1	0	1
M3	1	1	1	0
	2	1	1	0
	3	1	1	0
M4	1	1	0	1
	2	1	0	0
M5	2	1	1	1
		1	1	1
M6	2	0	0	0
		0	0	0
M7	2	0	0	0
M8	1	1	1	1
	1	1	1	1
	2	1	1	1
		1	0	1
M9	1	1	1	1
		1	0	0
M10	1	1	0	0
Total =				

ZONE	STAGE	SAR1	SAR 2	SAR 3
D1	1	1	0	1
	2	1	0	1
D2	1	0	0	1
	2	0	0	1
D3	1	1	0	1
D4	1	1	0	1
	2	0	0	1
D5	1	0	0	0
	2	0	0	0
Total =				

ZONE	STAGE	SAR 1	SAR 2	SAR 3
A1	1	1	0	1
	2	1	0	
A2	1	0	0	1
	2	0	0	
	3	0	0	1
A3	1	1	0	1
	2	1		
	3	0	1	1
A4	1	1	0	1
	2	1	0	0
A5	1	1	0	1
	2	1	0	1
A6	1	0		
	2	0	1	0
	3	1	0	1
Total =				

ZONE	STAGE	SAR 1	SAR 2	SAR 3
E/E1	1	1		
	1	1	0	0
	0	0	0	0
E/E2		1	1	
	2	0	1	1
	3	0	1	0
E/E3	1	1	0	
	2	1		1
E/E4	1	0	1	
	2	0	1	0
E/E5	1	1	1	1
	2	0	1	
E/E6		1	1	0
	2	1	1	
	3	1	1	1
		1	1	
E/E7	1	1	1	1
	2	0	1	0
	3	1	1	0
Total =				

TABLE IV: Initial spreadsheet output showing multiple impacts

ZONE	STAGE	SAR1	SAR 2	SAR3	ZONE/STAGE MULTIPLE IMPACTS	ZONE	STAGE	SAR1	SAR 2	SAR 3	ZONE/STAGE MULTIPLE IMPACTS
M1	1	1	1	1	1	A1	1	1	0	1	1
	2		1	1	1	A2	1	0	0	1	0
M2	1	1		1	1		2	0	0	1	
	2	0	1	1	1		3	0			0
	3	1	0	1	1	A3	1	0	0	1	1
M3	1	1	1	0	1		0	0	0	1	0
	2		1	0	1	A4	1	1			1
	3	1	1	0	1		2	1	0	1	
M4	1	1	0	1	1	A5	1	1	0	1	0
	2	1	0	0	0		1	1			1
M5	1	1	1	1	1	A6			0	0	0
	2	1	1	1	1		2	0	0	0	0
M6	1	0	0	0	0		3	1	0	1	1
	2	0	0	0	0	Total =		9	0	13	8
M7	1		1	1	1						
M8	1	1	1	1	1						
	2	1	1	1	1						
M9	1		0	1	1						
	2	1	1	1	1						
M10	1	1	0	0	0						
	2	1	0	0	0						
Total =		18	12	13	16						

ZONE	STAGE	SAR1	SAR 2	SAR 3	ZONE/STAGE MULTIPLE IMPACTS	ZONE	STAGE	SAR 1	SAR 2	SAR 3	ZONE/STAGE MULTIPLE IMPACTS
D1	1	1	0	1	1	E/E1	1	1	1	0	1
	2	1	0	1	1		3	0	0	0	1
	3		0	1	0	E/E2	1	1	1	1	1
D2	1	0	0	1	0		3	0	0	0	0
D3	1	1	0	1	1	E/E3	1	0	0	1	1
D4	1	1	0	1	1	E/E4	1	0	1	1	
	2	0	0	1	0				1	0	0
D5	1	0				E/E5	1	1	1	1	1
	2	0	0		0				1	1	1
Total =		4	0	7	4	E/E6	1	1	1	0	1
							2	1	1	1	
							3	1	1	0	1
							4	1	1	0	
						E/E7	1	1	1	1	1
							3	1	1	0	1
						Total =		12	15	9	14

TABLE V: Spreadsheet matrix for entering man-hour estimates

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOURL ESTIMATE	SAR 2 MANHOURL ESTIMATE	SAR 3 MANHOURL ESTIMATE	ESTIMATED MANHOURL SAVINGS	ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOURL ESTIMATE	SAR 2 MANHOURL ESTIMATE	SAR 3 MANHOURL ESTIMATE	ESTIMATED MANHOURL SAVINGS
M1	1	1					A1	1	1				
	2	1						2	1				
M2	1	1					A2	1	0				
	2	1						2	0				
	3	1						3	0				
M3	1	1					A3	1	1				
	2	1						2	1				
	3	1						3	0				
M4	1	1					A4	1	1				
	2	0						2	0				
M5	1	1					A5	1	1				
	2	1						2	1				
M6	1	0					A6	1	0				
	2	0						2	0				
M7	1	1						3	1				
M8	1	1					Total =		8				
	2	1											
M9	1	1											
	2	1											
M10	1	0											
	2	0											
Total =		16											

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOURL ESTIMATE	SAR 2 MANHOURL ESTIMATE	SAR 3 MANHOURL ESTIMATE	ESTIMATED MANHOURL SAVINGS	ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOURL ESTIMATE	SAR 2 MANHOURL ESTIMATE	SAR 3 MANHOURL ESTIMATE	ESTIMATED MANHOURL SAVINGS
D1	1	1					E/E1	1	1				
	2	1						2	1				
	3							3	0				
D2	1	0					E/E2	1	1				
	2	0						2	1				
D3	1	1					E/E3	1	0				
D4	1	1					E/E4	1	1				
	2	0						2	0				
D5	1	1					E/E5	2	1				
	2	0						1	1				
	3	0					E/E6	1	1				
	4	1						4	1				
	5	1					E/E7	1	1				
	6	0						2	0				
Total =		4					Total =		14				
							OVERALL TOTAL =		42				

appropriate cells in the spreadsheet. Since the ShipAlt designers are alerted to areas of potential synergistic cost savings per pallet, estimates of these savings can be made. This data can then be input into the spreadsheet to permit easy compilation of the total savings associated with zone/stage combination of ShipAlts. Simple manipulation of the spreadsheet permits evaluation of a number of different ShipAlt combinations for potential synergistic savings. Table V shows the spreadsheet into which data is entered as the design process has progressed. Now, man-hour estimates for ShipAlt work by pallet can be input. The

estimated savings by combining work from different ShipAlts involving the same pallet can also be input into the appropriate cell in the spreadsheet. Table VI is a final spreadsheet output, indicating all pallets impacted by all ShipAlts being considered, and also providing total cost estimates and synergistic cost savings.

The spreadsheets shown here were programmed using LOTUS 1-2-3. The procedure to set up such a spreadsheet matrix (using LOTUS 1-2-3 or any other spreadsheet software) is relatively straightforward.

TABLE VI: Final spreadsheet matrix

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOUR ESTIMATE	SAR 2 MANHOUR ESTIMATE	SAR 3 MANHOUR ESTIMATE	ESTIMATED MANHOUR SAVINGS
M1	1	1	35	53	87	34
	2	1	66	46	53	71
M2	1	1	35	0	64	28
	2	1	0	25	34	0
	3	1	68	0	35	35
M3	1	1	76	78	0	33
	2	1	68	35	0	12
	3	1	46	84	0	42
M4	1	1	86	0	97	75
	2	0	56	0	0	0
M5	1	1	46	23	53	32
	2	1	46	26	68	57
M6	1	0	0	0	0	0
	2	0	0	0	0	0
M7	1	1	57	37	86	57
M8	1	1	86	26	54	46
	2	1	25	74	54	12
M9	1	1	25	0	87	0
	2	1	75	54	76	46
M10	1	0	75	0	0	0
	2	0	68	0	0	0
Total =		16	1039	561	848	580

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOUR ESTIMATE	SAR 2 MANHOUR ESTIMATE	SAR 3 MANHOUR ESTIMATE	ESTIMATED MANHOUR SAVINGS
D1	1	1	46	0	45	37
	2	1	46	0	68	26
D2	1	0	0	0	86	0
	2	0	0	0	34	0
D3	1	1	57	0	86	38
	2	0	0	0	54	0
D4	1	1	86	0	54	46
	2	0	0	0	54	0
D5	1	0	0	0	0	0
	2	0	0	0	0	0
Total =		4	235	0	427	147

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOUR ESTIMATE	SAR 2 MANHOUR ESTIMATE	SAR 3 MANHOUR ESTIMATE	ESTIMATED MANHOUR SAVINGS
A1	1	1	46	0	63	33
	2	1	78	0	56	50
A2	1	0	0	0	64	0
	2	0	0	0	65	0
	3	0	0	0	26	0
A3	1	1	37	0	32	17
	2	1	54	0	34	25
	3	0	0	0	86	0
A4	1	1	31	0	65	22
	2	0	56	0	0	0
A5	1	1	46	0	45	0
	2	1	46	0	68	41
A6	1	0	0	0	86	0
	2	0	0	0	0	0
	3	1	46	0	68	33
Total =		8	440	0	758	221

ZONE	STAGE	ZONE/STAGE MULTIPLE IMPACTS	SAR 1 MANHOUR ESTIMATE	SAR 2 MANHOUR ESTIMATE	SAR 3 MANHOUR ESTIMATE	ESTIMATED MANHOUR SAVINGS
E/E1	1	1	4	45	0	4
	2	1	46	0	68	39
	3	0	0	0	0	0
E/E2	1	1	75	75	86	43
	2	1	0	35	86	13
	3	0	0	76	0	0
E/E3	1	0	46	0	0	0
	2	1	36	0	68	31
E/E4	1	1	0	34	86	13
	2	0	0	32	0	0
E/E5	1	1	86	34	54	46
	2	1	0	43	54	0
E/E6	1	1	43	53	0	15
	2	1	75	36	76	46
	3	1	75	54	0	41
	4	1	75	34	0	24
E/E7	1	1	68	35	57	53
	2	0	0	87	0	0
	3	1	75	87	0	50
Total =		14	704	760	635	423
OVERALL TOTALS =		42	2418	1321	2668	1371

RECOMMENDATIONS

1. IMPROVE THE MANUFACTURING SYSTEM

There is great need for OpNav and NavSea to recognize that a shipyard's ability to improve itself while implementing ShipAlt work is just as much a military requirement as upgrading weapons systems in warships. Fortunately, virtually all military and technical improvements can be achieved while simultaneously and manifestly providing for manufacturing system improvement.

OpNav should state, "A shipyard's ability to improve its manufacturing system during implementation of any work is a military requirement."

NavSea should state in The Fleet Modernization Program Management and Operations Manual, "Shipyards shall provide for improvements in their manufacturing systems during ShipAlt implementation."

Significant improvement is dependent upon concerted application of all of the basic management functions, that is:

- estimating,
- planning (design is an aspect of planning),
- scheduling,
- implementing (both material marshalling and producing), and
- evaluating.

Therefore, with particular emphasis on those who participate in developing contract requirements, a manufacturing system must be regarded as including all organizations that influence how shipyards perform. For ShipAlt work they include:

- Ship Logistics Managers (SLMs) /Program Managers (PMs),
- Type Commanders (TyComs),
- Engineering Directorates (EDs), and
- planning yards.

SLMs, PMs, TyComs, and EDs are customers. They should understand that their best interests are served when their military and technical requirements are formatted in a way that permits further refinement and eventual implementation per modern, zone oriented manufacturing technology.

Planning yards serve two masters. They function as agents of customers during their preparation of:

- ShipAlt Records, that is, preliminary design activities that are sufficient for ShipAlt programming decisions, and
- SIDs that have the effect of contract drawings.

And they serve implementing shipyards during their preparation of such other SIDs that are required.

OpNav should state, "Because contract design is part of the manufacturing system, SLMs/PMs, Tycoms, and EDs, shall negotiate, preferably with implementing yards, but otherwise with planning yards acting as surrogates, for the purpose of incorporating effective implementation strategies in contract drawings."

2. DEVELOP GENERIC STRATEGIES PER SHIP CLASS

Zone/stage control of work combined with addressing each type of work separately (for example, light-fitting rip out and heavy-fitting rip out), are all that are needed to devise a very useful, generic alteration strategy by ship class. That part of a strategy that applies to a single specialty within one ship class, say for machinery spaces, since it is by type of work, will be similar to that required for another ship class. Thus, very much can be adapted from class to class by just taking into account the different compartmentation.

OpNav should authorize a special project for the purpose of developing generic strategies that planning yards should use to preview how zone oriented work is most likely to be implemented.

NavSea should direct planning yards to provide codes in their design models so that they can offer implementing yards a choice of information in zone/stage groups that match a generic strategy or in traditional system-by-system groups.

3. INSTITUTE ZONE ORIENTED DESIGN STAGES

Contract and functional design are distinct stages in a traditional design approach. Transition and work instruction design stages do not exist. Zone orientation features system-by-system expertise applied to functional matters and initial material definition, but it also relies on zone oriented expertise per regional specialty, particularly for detail design and exact material definition. As more than two thirds of design man-hours are spent on detail design, the corporate culture

will change for the majority involved in ShipAlt design efforts.

The change will entail a culture shock for many who believe they have achieved security by commanding design aspects of a particular function. Their vision cannot be expected to include optimizing implementation of entire ShipAlts nor their roles as de facto participants in a manufacturing system which has the obligation to continually improve.

NavSea should provide special assistance to planning yards in the form of programs to indoctrinate designers in zone logic, to identify people who cannot make the transformation, and to provide such people with other work or early retirement.

NavSea should require planning yards to implement the four distinct zone logic design stages, including, contract, functional, transition, and work instruction.

4. ESTABLISH PRODUCTION ENGINEERING IN PLANNING YARDS

Although a generic strategy per a ship type would be available, each planning yard would still require its own production engineers. They would be required at first to adjust a generic strategy in the context of a particular set of ShipAlts authorized for simultaneous implementation. Until an implementing yard is designated, planning yard production engineers would have to refine their strategy as design progress makes more information available.

NavSea should require each planning yard to develop a production engineering capability for each specialty represented in the ship classes assigned to them. Each person so assigned should have keen understanding of ship operational, ship maintenance, and shipyard manufacturing system matters for the specialty assigned.

5. SHIFT TO PRODUCT ORIENTED MATERIAL MANAGEMENT

Since material is the only tangible, the most effective shipyard management systems control production through control of material. Consumed man-hours are reported per physical characteristic of the interim products completed and according to the problems they impose, for example, man-hours: per length of electric-cable pulled separately for large, medium and small diameters; per pipe pieces fabricated separately by pipe-piece family; and per weight of electronic work packages separately for shop assembly and for on board assembly.

Statistical analyses of man-hour cost returns identify how such work normally (mean values and standard deviations) performs and are the bases for man-hour budgeting and scheduling. When constant comparisons by computer disclose material types or volumes defined during any design stage that exceed those in the contract design material budget, budgeted man-hours increase accordingly and schedules have to be confirmed or adjusted. In order to maintain the validity of the material/man-hour corporate data, certain material management techniques are required.

Since they influence material/man-hour relationships, certain U.S. Navy purchasing activities, and material suppliers including those for Centrally Provided Material (CFM) are also de facto parts of a yard's manufacturing system. In other words both material and production responsibilities are operational matters that should respond to the same ship modernization strategy. Further, the productivity of a manufacturing system is dependent upon knowing beforehand how material suppliers will perform as well as how their products will perform. Therefore operational considerations should be the primary basis for procurement regulations that shipyards must follow.

OpNav should, except for CPM and LLTM necessarily ordered before an implementing yard is designated, transfer all remaining material procurement responsibilities to implementing yards. This recommendation is peculiar to naval shipyards because they are required to employ purchasing activities outside of their commands for a significant part of their material procurement activities.

NavSea should work to remove any restrictions that may exist that prevent shipyards from initially ordering certain materials from diagrammatics, and from limiting the number of eligible bidders for productivity reasons. Large amounts of corporate data are essential for a modern manufacturing system. Regarding each product, this includes design details, approval status, quality, accuracy, ILS, prices, scheduled delivery record, and guarantee service record. Attempting to build the needed file of corporate data without limiting the number of prospective bidders for each item to no more than three, is simply impractical.

NavSea should require naval shipyards, and should recommend to private shipyards, that they employ the allocated stock (AS) material management concept.

NavSea should require naval shipyards, and should recommend to private

shipyards, that they relate materials to man-hours.

NavSea should require naval shipyards, and should recommend to private shipyards, that they employ a computer to constantly compare materials being defined in later design stages to material budgets developed during contract design.

6. GENERAL

NavSea, as well as all those involved in the construction, modernization, overhaul and repair of naval ships, have a critical need to reexamine the way in which information, people, material and work are organized. Although the benefits of exploiting zone technology in production work are generally recognized, the rest of the manufacturing system has not been evaluated and altered to suit this approach. In general, most participants in the manufacturing system continue to employ system-by-system thinking for all preparations leading to production. Just before production starts, attempts are then made to reorganize information to utilize zone technology in production. One strategy is employed until production work is to start, and then a switch to a completely different one is made. This situation is the result of a manufacturing system that has evolved over many years.

This paper sets forth the premise that all parts of the ship modernization, overhaul and repair process should be recognized as being part of one manufacturing system. Thus the activities of planning yards are a critical part. Further, specific guidance for how planning yards should go about preparing ShipAlt information in order to facilitate implementation of zone logic is provided. OpNav and NavSea should review, evaluate and act upon these recommendations as a means of improving its ability to manage the construction, modernization, overhaul and repair of the naval fleet. As a practical matter, Navsea should revise and update the FMP Manual to reflect the goal of supporting and encouraging the productivity gains that can be achieved by employing zone logic in ship repair, overhaul and modernization programs. Suggestions for many of the revisions are provided in Part 3 of the report to Panel SP-4, upon which this paper is based.

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Improving Overhaul Planning Through Risk Assessment and Risk Management

VIA-3

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ABSTRACT

The execution of the overhaul of US. Naval vessels at a public shipyard is fraught with risk. Far too often the work authorization process is constrained by a limited budget. This situation can result in two common outcomes:

1. The shipyard delivers a ship to the customer that has significant repair work either deferred or incomplete; and

2. The deferred or incomplete work is screened back to the Shipyard late in the overhaul, forcing an upheaval in the logical planning and execution of the availability.

Risk affects both the shipyard and ship's force because the completion of the overhaul could be affected by late authorized work resulting in the ship not being able to meet her commitments.

As Philadelphia Naval Shipyard (PNSY) is an industry leader in zone or Group Technology execution methods, it is particularly disruptive to work flow to return to geographic areas and perform work in an area out of phase or even worse-in an area where similar work is already complete.

In the past the tools that were most often employed to build an effective work package, yet still remain within the budget, were personal experience, historical data and trends, and the necessary deletions of less critical work in favor of accomplishing essential repairs. The shipyard's success at making these determinations was held hostage by purely subjective opinions of the particular group of advance planners that attended the Work Definition Conference (WDC) and executed most of the advanced planning, without consideration of established overhaul objectives.

With the innovation of Zone Technology, it was clear that a consistent and effective risk assessment method must be developed to determine the probability of equipment failure during the testing phase of the overhaul and the impact on cost and schedule to the overhaul. The USS KIDD (DD-963)

scheduled availability in 1989 proved to be the ideal opportunity to develop and execute a formal risk assessment and management program. The USS CONSTELLATION (CV-64) SLEP availability in 1990 afforded the opportunity to refine and expand the risk assessment methodology.

ACRONYMS AND DEFINITIONS

AAW: Anti Aircraft Warfare.

ALRE: Aircraft Launch and Recovery Equipment (Catapults, Arresting Gear, etc.)

APL: Allowance Parts List.

CASREP: Casualty Reporting System.

CNO: Chief of Naval Operations.

CSMP: Current Ships Maintenance Program.

ETC: Equipment Identification Code.

IEM: Inactive Equipment Maintenance.

LOE: Light Off Examination.

MCC: Mission Criticality Code.

NAVAIR: Naval Air Systems Command.

NAVSEA: Naval Sea Systems Command

NAVSES: Naval Ship Systems Engineering Station

NIU: New Threat Upgrade.

PEC: Predicted End Cost.

POT&I: Pre-Overhaul Test and Inspection.

RSR: Readiness Support Group.

SARP: Ship Alteration and Repair Package.

SIAT: Ship Installation Acceptance Test (Performed on Weapons Elevators).

SIMA: Ships Intermediate Maintenance Activity.

SPCC: Ships Parts Control Center.
SLEP: Service Life Extension Program.
T&C: Test and Certification.
WDC: Work Definition Conference.

INTRODUCTION

The success of an overhaul of a U.S. Navy ship depends on clearly defined overhaul objectives and a work package that supports these objectives. A work package consists of those repairs that are initially authorized, new items requiring repair identified during the overhaul, and growth which is an increase in the scope of repairs on a piece of equipment or system already being accomplished during the overhaul. Being able to accurately predict the end cost of an overhaul (i.e. projecting the amount of growth and new work to expect during the overhaul) is also a function of how well the total work package meets the overhaul objectives.

For a work package to satisfy the final objectives, these objectives must be strictly defined and a maintenance strategy clearly delineated. The maintenance manager must determine the truly necessary repairs and ensure those repairs are assigned to the groups with the capability and capacity to accomplish them within budget and schedule. Other less critical items must be identified and deferred for future availabilities or scheduled for accomplishment based upon schedule and shop loading. This action reduces the overall affect on cost and schedule by keeping introduction focus on the most critical jobs and at the same time helps to ensure a stable work force.

Shipyard risk on impacting cost and schedule of an overhaul is minimized by executing authorized work, ensuring overhaul objectives are met, and completing an availability on schedule. It is important that the proper repairs are authorized and consideration be given to reduce risk. Late identification of repairs based on testing can be avoided and problem areas identified through early diagnosis of cost and schedule drivers.

Risk assessment is not a new concept. Reliability and maintainability studies have been accomplished to determine mean time between failure of components in order to predict when that component should be overhauled. Most assessments take the maintenance manager's perspective and use risk analysis to assist in defining what needs an overhaul and ensure funds are not used to overhaul equipment unnecessarily. This paper assumes the perspective of the shipyard and provides a management tool that addresses the shipyard's in accomplishing late authorized work and provides a course of action that ensures the

work package is executable. Studies in the past used risk assessment to define the work, while availability of funds determined what actually was authorized. Funding constraints result in the shipyard assuming the risk of completing the authorized work on schedule, demonstrating those repairs, accomplishing system level testing and sea trials. It is during the testing phase when the greatest risk is revealed, generally resulting in late authorized work which, when using Zone Technology is accomplished out of sequence causing unnecessary delays and disruption as well as increased costs.

OVERVIEW

Risk assessment was first used during the USS KIDD overhaul and subsequently used on the USS CONSTELLATION as a management tool to define the work to be accomplished. An overview of the USS KIDD and USS CONDITION overhauls are described as follows:

USS KIDD Overhaul

The New Threat Upgrade (NTU) Program was initiated in the mid-seventies to improve the performance of the Anti-Aircraft Warfare (AAW) system on Navy cruisers. It was designed to improve the ability of the Terrier and Tartar ships to detect, track and engage antiship missiles. The NTU provides the ships with a modern AAW detection, tracking and target engagement system (1).

USS KIDD was the fourth ship to undergo the NTU overhaul. The work package was developed using traditional planning techniques including Pre-overhaul Test and Inspections (POT & I)'s. Current Ship's Maintenance Program (CSMP) and experience gained from the previous NTU availabilities. Nearly 54,000 mandays were identified for repairs. Funding constraints resulted in 23,206 mandays authorized at the Work Definition Conference (WDC). An additional 7,500 mandays were authorized after the Ship's Force WDC.

As a result of the funding constraints, the ship's force work package was significantly larger than in previous NTU availabilities. Much of their work was directed to a Shore Intermediate Maintenance Activity (SIMA). The Ship's force was provided a shipyard schedule which identified when their items and the SIMA items were required to be completed in order to support testing. When the ship arrived at the shipyard, work that was initially screened to ship's force and SIMA began to be re-screened to the shipyard because ship's force did not have the capability or capacity to accomplish all of their work. Recognizing potential problems, a risk assessment of the work not being accomplished by the shipyard was performed in order to develop contingency plans for executing late authorized work and

to accurately predict the end-cost of the availability. As previously stated, late authorized work is disruptive, impacts the schedule and is costly due to doing work out of sequence often resulting in rework. The basis of the risk assessment was to ensure that the Navy's overhaul completion criteria were met (2).

USS CONSTELLATION Overhaul

CV SLEP grew from an investigation in the mid-seventies initiated by Chief of Naval Operations, (CNO) Admiral Holloway, to determine alternatives to new construction for maintaining aircraft carrier force levels into the twenty first century.

Admiral Holloway's goal was to extend the service life of fossil fueled carriers by fifteen years, thereby ensuring their reliability for effective combat Operations with only routine maintenance through the extended service life. This goal was thought feasible through execution of an availability which stressed previously deferred structural and auxiliary system repairs along with replacement of equipment and systems for which logistics support is no longer attainable.

USS CONSTELLATION is the fifth Ship to undergo SLEP at the shipyard. The work package was developed using traditional planning techniques. A pre-authorized work package based on historical work authorization provided a baseline. Pre-overhaul Test and Inspections (POT & I) were conducted with extra emphasis placed on known problem areas and lessons learned from previous availabilities. This planning effort resulted in identifying nearly 1,400,000 mandays of known repairs and was based on overhaul objectives developed for previous SLEP availabilities.

The USS CONSTELLATION SLEP budget was reduced 35% by the US Congress. This reduction resulted in only 664,000 mandays authorized at the WDC as opposed to over 1 million mandays authorized at the WDC for the previous ships undergoing SLEP. The assignment of work at the WDC did not consider SLEP objectives and were based strictly on funding constraints. The result was a poorly defined overhaul for the ship with excessive work being accomplished by ship's force. The nature of the work differed from previous SLEPs in that several critical systems had responsibility split between ship's force and the shipyard.

Ship's force work also differed significantly from previous SLEPs. Ship's force was responsible for accomplishing more critical work than previously, requiring greater coordination with the shipyard's work, closer alignment with the Shipyard's schedule and greater involvement in the test and certification program. In order to ensure that an executable overhaul was

authorized, a risk assessment was conducted on the following areas as of concern:

1. Work not screened to the shipyard:
2. Work screened to the shipyard but partially funded and:
3. Work that was screened to the shipyard and fully funded.

METHODOLOGY

It was necessary to develop a method to quantify risk, taking into consideration the capability and capacity of the overhauling agent and ensuring the customers objectives would be met. The risk assessment procedure developed for USS KIDD as described below and was based on ranking the work using basic risk categories.

The approach used for conducting the USS KIDD risk assessment was reviewed for use on USS CONSTELLATION. The difference in size, complexity, and duration of the two availabilities required expanding the assessment technique. Consideration had to be given to intermediate milestones, an expanded test and certification program and to Ship's force work. The fact that no formal objectives existed for USS CONSTELLATION also factor in determining the procedure utilized.

USS ASSESSMENT PROCEDURES

The work package review and risk analysis for USS KIDD considered the work assigned to Ship's Force, SIMA Headiness Support Group (RSG), Naval Ship Systems Engineering Station (NAVSES): as well, as deferred items. The work was reviewed with Particular attention to those equipments and systems of which potential failure of a particular piece of equipment could result in new work being assigned to the Shipyard late in the availability. Testing and schedule risks were also assessed. This assessment was accomplished by the project manager who had the greatest experience and knowledge of USS KIDD's planning and work package.

The assessment criteria for each item included the following:

1. Listing of repair items that were the responsibility of ship's force:
2. Ship's force generated deficiency report that identified known work:
3. Light Off Examination/Test Critical (Yes or No) :
4. Ship Mission Critical (Yes or No)-(based on known overhaul objectives):
5. Risk of Failing during testing (Low, Medium or High)

6. Test Impact Risk (Low Medium or High) and:

7. Schedule Impact Risk (Low, Medium or High).

The three risk categories (Failure. Test and Schedule) were assigned the following values by the project manager while considering the overhaul objectives:

1. .50 for new work that is considered High Risk.
2. .40 for new work that is considered Medium Risk, and
3. .10 for new work that is considered Low Risk.

A cumulative risk was calculated by summing the High, Medium or Low risk values for each item resulting in a weight factor less than 1.0. The weight factor multiplied by the estimated cost measured in mandays resulted in the weighted mandays or growth reserve anticipated.

The sum of the weighted mandays or growth reserve. when added to the current sales estimate provided the Predicted End cost (PEC) for the overhaul. The PEC was monitored and tracked throughout the overhaul.

The risk assessment provided data that allowed shipyard managers to submit two fixed price offers for USS KIDD. The first fixed price offer used traditional procedures for predicting the end cost of each item being repaired based on physical progress of that item. The second but higher fixed price offer, took into consideration the risk assessment as well as the data used for the first fixed price. This was calculated by adding the weighted mandays from the risk assessment to the predicted end cost of all the work being accomplished during the overhaul. The higher fixed price offer was based on the shipyard assuming the risk for all-new work and/or growth and assuming that no catastrophic failures outside the normal scope of overhaul work would occur.

The lower offer. without the risk assessment being considered, was accepted. The shipyard continued to monitor the high risk items and track the costs for additional work anticipated to be authorized in accomplishing the high risk items. Contingency plans were made by reviewing material availability. ordering the most critical long lead time items and ensuring documentation was available for accomplishing repairs on those items categorized as high risk. The contingency planning was done to lessen the impact when and if the high risk items were authorized for shipyard accomplishment.

USS CONSTELLATION RISK ASSEMENT PROCEDURES

The process used for risk assessment on USS KIDD was based on a relatively small work package. The size and complexity of USS CONSTELLATION'S overhaul required establishment of a detailed step by step procedure.

Resources used to conduct the risk analysis for the USS CONSTELLATION included shipyard personnel. primarily from the SLEP Project Office. Combat Systems and the Hull propulsion and Auxiliary Test Branch. U.S. Navy from the Type Commander Staff experts were used where specific fleet experience was required and specialists were called in for combat systems. aircraft launch and recovery and main propulsion. The outside resources served two functions, providing an independent analysis that reviewed and validated shipyard data and augmented organic resources with fleet experience.

The risk assessment was based on two factors as described by Bertrum Smith. Jr. (3):

1. Probability of equipment Failure
2. Consequences of equipment Failure

Probability of failure takes into consideration a maintenance burden factor, or how often something fails. This portion of the analysis was purely objective because the source of information was a report from the Naval Sea Logistics Center titled "Logistics High Failure Equipment" (4). This report lists the top 300 equipment by Equipment Identification Code (EIC) for each ship. A numerical value was assigned based on where that piece of equipment was in the top 300 listing. It should be noted that the report covered only Naval Sea Systems Command (NAVSEA) cognizant equipment. Naval Air systems command (NAVAIR) cognizant equipment was assigned scores by knowledgeable personnel assigned to the risk assessment team who had been thoroughly briefed on the concepts involved.

Consequences of failure were based on mission impact and availability impact. The sources of data included mission criticality studies for other classes of ships and the matrix and logic tree shown in Figure (1). This portion of the analysis was also objective and tailored the results to be consistent with the Navy's Casualty Reporting (CASREP) system.

The risk impact on the availability was determined using the following criteria:

1. Impact on the Shipyard
 - a. Test/Certification
 - b. Schedule Events (7)

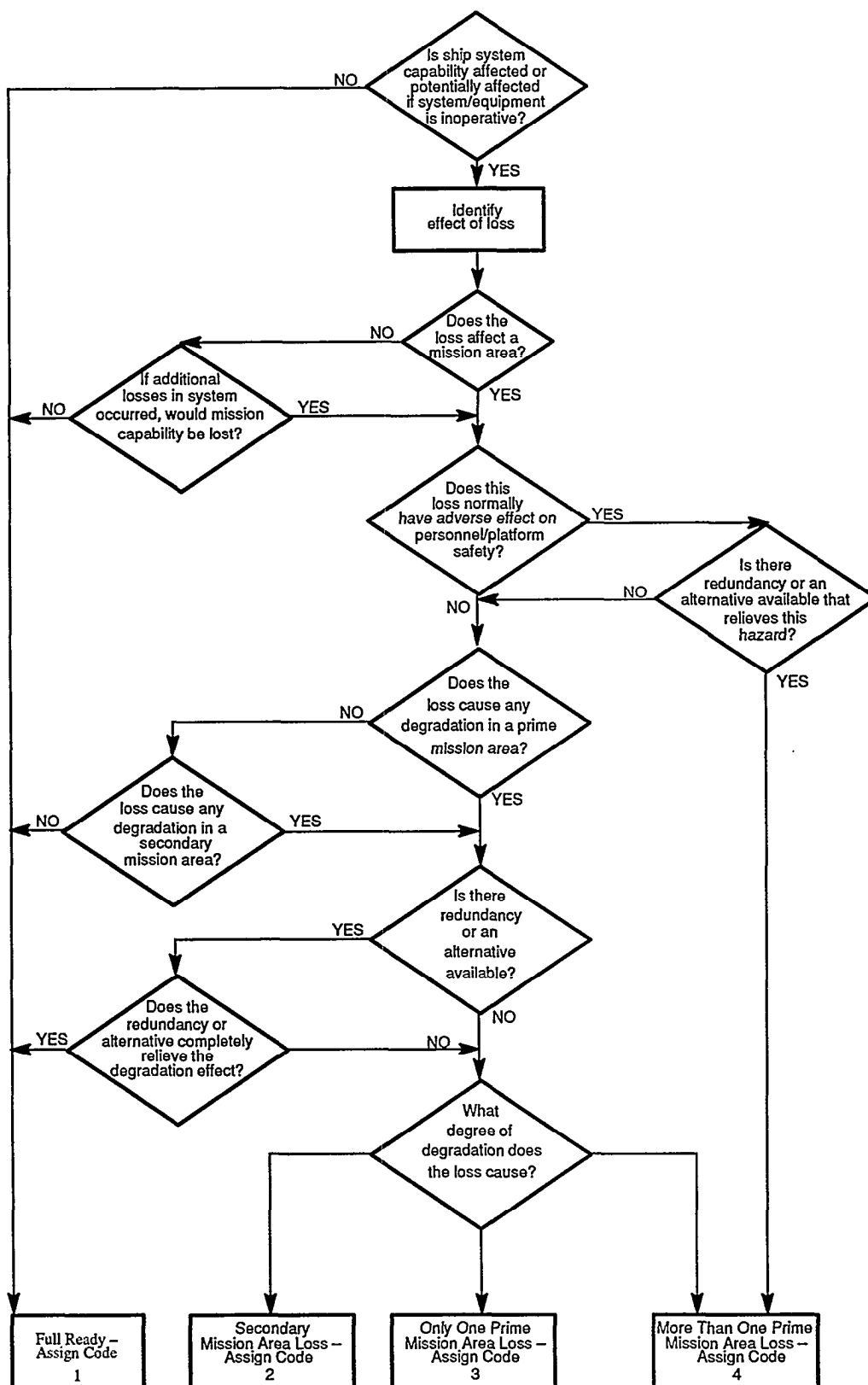


Figure 1
Mission Criticality Decision Logic Tree

- a. Impact on Ship's Force
 - a. Capability
 - b. Workload

Schedule impact included impact on major events such as undocking, Light Off Exams (LOE'S), Ship Installation Acceptability Tests (STAT), Aircraft Launch and Recovery Equipment (AIRE) certification. crew move aboard. complete availability, etc. Impact on ship's force also considered work screened to various intermediate maintenance activities.

The U.S. Navy's contract to a Shipyard for a ship under overhaul known as the Proposed Ship Alteration and Repair Package (SARP) (Prepared by the Shipyard in June 1989 for WDC Use) was divided into four categories as listed below and used in the analysis:

1. Category I: Work not authorized to the shipyard:
2. Category II: Work authorized to the shipyard but only partially funded:
3. Category III: Work authorized the Shipyard and fully funded:
4. Category IV: Modernization items or Ship Alterations.

Category I included all work authorized to the ship's force. SIMA and not authorized/deferred. Category II and III were determined by taking the mathematical average for similar work from previous SLEP availabilities. If the **CONSTELLATION** estimate was 79% or less than the average. it was placed in Category II: if it was 80% or greater in Category III. This process was followed for each line item in the SARP in each of the four categories.

The work sheet utilized is shown in Figure 2. The basic information was extracted from the USS **CONSTELLATION** computerized SARP data base.

RANKING THE RESULTS

Values from 1 to 5 (1 being least likely to impact the overhaul schedule if repairs were identified late. 5 being most likely to impact the overhaul schedule) were assigned to each of the parameters discussed later in this paper with the exception of Mission Criticality which had a maximum score of 4.

Adding the scores for each parameter, and dividing by 29 (the maximum possible score) resulted in a calculated weighting factor which did not exceed 1.0. Historical data was used to determine cost estimates where actual estimates did not exist. Estimates were multiplied by the weighting factor to obtain weighted costs.

PROBABILITY OF FAILURE

The Naval Sea Logistics Center publishes a report that sequentially ranks all reported equipment and displays the pieces of equipment that fail or break down and requires overhaul most frequently. Eight maintenance generated factors are quantified and ranked to determine a composite rank of each piece of equipment. These eight factors are weighted equally for the standard report. For each listed piece of equipment. as many as eleven Allowance Parts List (APL) Numbers/Equipment Identification Codes (EIC) are ranked. displaying nomenclature and percentage of repair actions to total times the piece of equipment requires overhaul. APLS/EICS are indexed on the final page of the report. Report option 03: EIC-All reported Data Option and 04: APL-ALL reported data for the USS **CONSTELLATION** for the Reporting Period June 1984 through February 1989 were received from the Naval Sea Logistics Center. The EIC (Option 03) was selected and used for ease of referencing to the system work breakdown structure.

Weighting Factor Scores were assigned in accordance with Table I where the highest ranking means that piece of equipment is more likely to fail.

Report Ranking	Score
1-50	5
51-100	4
101-150	3
151-200	2
201-ONWARD	1

TABLE I

CONSEQUENCES OF FAILURE

The Consequence(s) of Failure were divided into two areas: impact on ship's mission and impact on the overhaul completion.

Mission Related Impacts

The Navy Ship Parts Control Center (SPCC) in Mechanicsburg. PA. Provides a list of Mission Criticality Codes (MCCs) . a numeric code assigned to a system. equipment. or component in a specific application to denote its importance to the mission assignment of the military unit in which it is installed. MCCs consist of a numeric code of 1 through 4 to designate the importance of the system. equipment or component with 4 indicating the most significant and 1. the least. MCCs 1 through 4 correlate directly to Casualty Reporting (CASREP) codes severity (MCC 4 equivalent to C4 severity). Since operational alternatives and redundancies can reduce CASREP severity,

CONSTELLATION (CV-64) RISK ANALYSIS AND MANAGEMENT														
CATEGORY 3: SHIPYARD FULLY-FUNDED ITEMS														
BY SWLIN BY WORK PROCEDURE														
DATE: 08/30/89														
PAGE: 1														
SWLIN	WORK PROC	SCRM	M S	DESCRIPTION	LEVEL IMPACT	PROB FAIL	MISSION IMPACT	OVERHAUL IMPACT		--S/Y--- --S/F---		WGHT FACT	MANDAY ESTIMATE	WEIGHTED MANDAY ESTIMATE

22111	002.01	SY	3	BURNERS:	C	5	3	3	3	1	3	0.621	293	182
22111	002.02	SY	3	A. MANUFACTURE & TEST	C	5	1	3	2	5	1	0.586	46	27
22111	003.01	SY	3	CASING REPAIRS:	C	5	3	3	2	5	1	0.655	2082	1364
22111	004.01	SY	3	DRUM INTERNALS:	B	5	3	4	4	3	5	0.828	307	254
22111	005.01	SY	3	BOILER INDICATORS:	C	1	1	5	3	1	1	0.414	173	72
22111	006.01	SY	3	BOILER TESTS:	B	5	1	5	4	1	1	0.586	373	219
22111	007.01	SY	3	SUPERHEATERS:	A391	5	3	4	5	5	3	0.862	2436	2100
22111	008.01	SY	3	SOOT BLOWERS:	B	5	1	3	4	3	3	0.655	244	160
22111	009.01	SY	3	BOILER FOUNDATIONS & S	C	5	1	3	3	5	1	0.621	445	276
22111	011.01	SY	3	PRESSURE PARTS:	B	5	3	5	4	3	5	0.862	328	283
22111	012.01	SY	3	BOILER S.O.I. - (NAVSS	A391	5	1	1	5	5	1	0.621	390	242
22111	013.01	SY	3	REFRACTORY:	B	5	3	3	4	3	3	0.724	801	580
22111	014.01	SY	3	SAFETY VALVES:	A391	5	3	5	5	1	3	0.759	300	228
22111	016.01	SY	3	BOILER ISOLATION VALVE	B	5	3	5	4	1	3	0.724	331	240
22111	017.01	SY	3	WATERSIDE MAINTENANCE:	C	5	1	1	2	1	3	0.448	369	165
22111	018.01	SY	3	BOILER DESUPHTR ASSEMB	C	5	3	4	3	1	3	0.655	654	428
22111	019.01	SY	3	SIDEWALL & REARWALL RE	C	5	3	3	3	3	3	0.690	84	58

Figure 2
Impact Assessment Worksheet

this correlation is also applicable to MCC assignments. when identical systems. equipment or components are installed in a single military unit and support different missions, the highest MCC was applied. The MCC was assigned from the matrix in TABLE II.

Because an explicit MCC study does not exist for the USS CONSTELLATION, the Mission Criticality Decision Logic Tree shown in Figure 1 was utilized to define the MCC when appropriate. Additionally, the "Aircraft Carrier Material Condition and Readiness Study Report" (5) was utilized in conjunction with "Summary of Propulsion Auxiliary Machinery in Operation" extracted from the Operating Guide for Propulsion Machinery (6) to more clearly define the impact on the ship's ability to perform its primary mission. The Summary of Propulsion Auxiliary Machinery in Operation is included as Figure 3.

Structural repairs were evaluated by locating the work site on the ship's plans and assessing the impact on mission performance. For example, machinery space longitudinals were believed to have a high level of redundancy. be unlikely to fail suddenly and would therefore have a low MCC. Conversely, serious catapult trough deterioration could result in track cover. cylinder or water-brake misalignment and could therefore have a significantly higher KC.

Structural repair impact on ship certification and schedule events was evaluated at the same time. To use the previous example, machinery space longitudinals would not have any significant impact on T & C or on the schedule, whereas a deteriorated ladder in an escape trunk would likely result in a restrictive discrepancy. Much of the heavy structural work was assessed as beyond the capability of ship's force and as a significant workload burden for ship's force despite the low MCC. T & C. and schedule impacts.

Overhaul completion Related/Impacts

This category was divided into four segments.

The following table is an analysis of the impact on a Test or Certification if the item were to fail.

Shipyard Schedule Impact

The shipyard utilizes Zone Technology and Event Management (7) as the process to focus management attention on segments of an overhaul above key operation level that are large enough to be significant. small enough to be managed and of the substance to provide frequent clear progress markers without obscuring the issues. The scheduling system is based on a hierarchical

ALTERNATIVES FOR MISSION ACCOMPLISHMENT

IMPACT IF ALTERNATIVES FAIL

Redundant
systems/
equipments/
components
available

Alternatives Neither
[excluding redundancies
redundancies) nor other
available alternatives
available

3	4	4	Total loss of mobility (propulsion or life support).
2	3	4	Severe degradation of mobility. total loss of a primary mission.
1	2	3	Severe degradation of a primary mission
1	1	2	Total loss or severe degradation of a secondary mission.
	1	1	Minor mission impact.

MISSION CRITICALITY CODES

TABLE II

	SPEED SHAFT REVOLUTIONS	AHR 0	15 K 74	20 K 100	25 K 126	30 K 153	Full Power 170	*20% BLR Overload 140 (est)	Full Power Astern 82
# On SHIP	IDENTIFICATION								
4	Main Turbines in Use	0	4	4	4	4	4	4	4
4-M, 4-T	Main Condensate Pump	0	4-T	4-T	4-T	4-M, 4-T	4-M, 4-T	4-T	4-T
4-T	Main Circulating Pump	0	0	0	0	0	0	0	0
4	Main Air Ejectors	0	4	4	4	4	4	4	4
4-M, 4-T	Lube Oil Service Pump	0	4-T**	4-T**	4-T**	4-T**	4-T**	4-T**	4-T
4-M	Emer Lube Oil Service Pump	0	0	0	0	0	0	0	0
4	Attached Lub Oil Pump	0	4	4	4	4	4	4	4
4	Lube Oil Cooler	0	4	4	4	4	4	4	4
4	Gland Exhaust Fan	0	4	4	4	4	4	4	4
8	Boilers in Use	2	4*	4*	8	8	8	4*	8
12-T	Main Feed Pump	2-T	4-T	4-T	8-T	8-T	8-T	4-T	8-T
4-M, 8-T	Main Feed Booster Pump	2-M	4-T	4-T	4-M, 4-T	4-M, 4-T	2-M, 2-T	2-M, 2-T	4-M, 4-T
4-M	Emer Feed Booster and Reserve Transfer Pump		ASRQ	ASRQ	ASRQ	ASRQ	ASRQ	ASRQ	ASRQ
4	Deaerating Feed Tank	1	4	4	4	4	4	4	4
24-T	Forced Draft Blower	2-T	4-T	8-T	16-T	24-T	24-T	12-T	8-T
12-T	Fuel Oil Service Pump	0	4-T	4-T	8-T	8-T	8-T	4-T	8-T
4-M	Port Use FO Service Pump	2-M	0	0	0	0	0	0	0
8	Control Air Compressor	2	4	4	8	8	8	4	8
8	Turbo Generators In Use	2	6	6	6	8	8	8	8
8-M	Auxiliary Condensate Pump	2-M	6-M	6-M	6-M	8-M	8-M	8-M	8-M
8-M	Auxiliary Circulating Pump	2-M	6-M	6-M	6-M	8-M	8-M	8-M	8-M
8	Auxiliary Air Ejectors	2	6	6	6	8	8	8	8

It should be noted that all ratings are based on Equal Shaft Revolution, and these ratings will vary if shaft speeds are split, these values will also change in accordance with Catapults in use.

M = MOTOR DRIVEN

T = TURBINE DRIVEN

ASRQ = AS REQUIRED

** = IDLING

* = 4 BOILER OPERATION, 2 IN EACH OF 2 MACHINERY SPACES, CROSS-CONNECTED PLANT

Figure 3
Summary of Propulsion Auxiliary Machinery in Operation

CATEGORY	DEFINITION	SCORE
Major Impact	High probability of failing a major certification requirement (LOE, SIAT, ALRE etc.)	5
Significant Impact	Moderate probability of equipment/system failing a major certification. but one or more schedule "work arounds" exist.	4
Moderate Impact	Low probability of failing a major certification/moderate probability of failing a minor test or certification: schedule "float" exists.	3
Some Impact	Low probability exists of failing a minor test or certification. Corrective action can be accomplished in a short time without schedule impact.	2
Low Impact/ No Impact	No discernable probability of impact on any test or certification	1

SHIPYARD TEST & CERTIFICATION IMPACT

TABLE III

arrangement of events and a weekly monitoring of those events. The following definitions are provided:

A-Event or Key Event:
the highest level of events. A key event date cannot slip without seriously impacting the overall schedule.

B-Event or Milestone Event:
normally within the controlling oaths leading to key events.

C-Event or Schedule Event:
normally used to maintain momentum on a project by focusing management attention on completion of near term events.

The analysis is of the impact to the overhaul schedule if a piece of equipment or system were to fail during an overhaul is shown in Table IV.

CATEGORY	DEFINITION	SCORE
Major Impact	High probability of impacting an "A" level event.	5
Significant Impact	High probability of impacting a "B" level event, significant probability of impacting an "A" level event.	4
Moderate Impact	High probability of impacting a "C" level event. significant probability of impacting a "B" level event.	3
some Impact	Impact confined to <i>job</i> order level only	2
Low Impact/ No Impact	Impact confined to key operation level only	1

SHIPYARD SCHEDULE IMPACT

TABLE IV

Ship's Force Capability Impact Items

An analysis that measures whether the ship's force has the requisite skills to accomplish the assigned task is shown in Table V.

After a full set of data was entered for any given line item, a Weight Factor (WF) was calculated by summing the scores for probability of failure, mission impact, test and certification impact, schedule impact, ship's force capability and ship's force workload burden. This sum was divided by the

IMPACT ON SHIP'S FORCE- CAPABILITY

CATEGORY	DEFINITION	SCORE
Major Impact-	Beyond Ship's Force capability due to skills or equipment required	5
Moderate Impact	Ship's Force can do portions of job - "Assist Ships Force" (ASF) dollars required	3
Low Impact/ No Impact	Ships force can do without help	1

IMPACT ON SHIP'S FORCE - CAPABILITY

TABLE V

Ship's Force Workload Burden Impact Items

A measure in dollars in term of ship's force level of effort if the item were identified late in the availability. These repair items would also impact the shipyard unless ship's force were to redirect their assests based on historical ship's force work packages.

maximum possible value of (29), yielding a WE' less than 1.0.

CALCULATION OF WEIGHTING MANDAYS

Cost estimates (measured in mandays to accomplish the work) were obtained from

SHIP'S FORCE WORKLOAD BURDEN

CATEGORY	DEFINITION	SCORE
Significant Burden	Requires a major re-direction of Ship's Force assets. May have an impact on the Shipyard unless contractual alternatives exist. (An example would be providing firewatches which is accomplished by ship's force. If ship's force were not available to do firewatch services. this effort would require contractor support).	5
Moderate Burden	Some elements of Ships Force work will be deferred until after completion. (Painting/Tiling)	3
Low/None	Very minor job, no discernable impact	1

SHIP'S FORCE WORKLOAD BURDEN

TABLE VI

CALCULATION OF WEIGHTING FACTOR

The study was accomplished in phases by category. Points were assigned for each repair item at the SARP line item level. Data entry was performed at a variety of personal computers which allowed incremental data input.

either the Proposed SARP for USS CONSTELLATION, historical information contained in the current SARP for USS KITTY HAWK (CV63) SLEP or the COMPLETION SARP for USS INDEPENDANCE (CV-62) SLEP for similar work. The "Weighted Mandays" were calculated by multiplying the estimated costs by the

maximum Possible value of (29). Yielding a WF less than 1.0.

CALCULATION OF WEIGHTING MANDAYS

Cost estimates (measured in mandays to accomplish the work) were obtained from either the Proposed SARP for USS CONSTELLATION. historical information contained in the current SARP for USS KITTY HAWK (CV63) SLEP or the completion SARP for USS INDEPENDANCE (CV-62) SLEP for similar work. The 'Weighted Mandays' were calculated by multiplying the estimated costs by the Weighted Factor". The results were entered in the column titled Weighted Manday Estimate'. Weighted mandays for Category II High Risk items were calculated by subtracting the authorized mandays from the estimate to fully fund the item and multiplying this value by the Weighted Factor".

ESTABLISHING RISK LEVELS

High risk was defined for both mission impact and overhaul impact. For mission impact, high risk was defined as any line item in the SARP having a Mission Impact score greater than 3. This means the risk "threshold" was set below those items which result in mission degrading casualties.

High risk for overhaul impact was defined as any line item having an overhaul impact score greater than 14. Individual parameter "thresholds" were set as:

1. Test & Certification is greater than 4;
2. Schedule is greater than 4;
3. Shin Force Capability is greater than 3; and
4. Shin Force Workload Burden is greater than 3.

Scores greater than 14 defined items which have "High Risk" and therefore need additional consideration for authorization.

At this point it should be noted that a "hysteresis-like" phenomenon exists between the processes of reducing risk by "adding" work to and increasing risk by "subtracting" work from the work package described in the SARP. This phenomenon may be displayed graphically as shown in Figure 4.

For this study, the difference in level of risk between "High" and "Acceptable" was determined by the set of conditions defined above, and those for "Acceptable Risk" which are as follows:

1. Test & Certification less than 2:

2. Schedule less than 1:

3. Shin's force Capability less than 1:

4. Shin's force workload burden less than 1.

This indicates that weighting factor scores less than 5 define line items which have "Acceptable Risk." and are therefore candidates for deletion from the work package to permit the funds associated with them to be utilized in the authorization of high risk line items.

RANKING THE RESULTS

Several reports were generated in order to analyse the data that was collected and rank the results. The calculated Weighted Mandays" were ranked in three ways as follows:

A. By magnitude of weighted mandays.

B. By mission impact. and

C. By overhaul completion impact

This allowed the data to be reviewed and an analysis to determine what was an acceptable risk.

USS KIDD Risk Results

4,875 high risk weighted mandays were identified. These items included stern tube seals, lube oil flushes, main lube oil pumps, fire pumps, salt water service pumps, etc. A total of 4,475 mandays were ultimately authorized as additional work for the shipyard on USS KIDD late in the overhaul.

USS CONSTELLATION Risk Results

There were 8,859 line item in the USS CONSTELLATION'S SARP. After the rating and ranking process and the application of "High Risk" criterion previously discussed, the number of line items which required close study. Possible re-assigning to the shipyard and/or additional funding was reduced to 1,172. These items were from both Category I as defined in the USS CONSTELLATION risk assessment Procedure (594 line items not screened to shipyard) and Category II (578 line items not fully funded). This meant that parties to the WDC, including the shipyard, NAVSEA, and shin's force could concentrate their efforts on 13.2 percent of the total line item.. rather than the entire package. for determining changes. The reports because an integral part of the decision making process with frequent references made throughout the WDC.

The availability of mandays associated

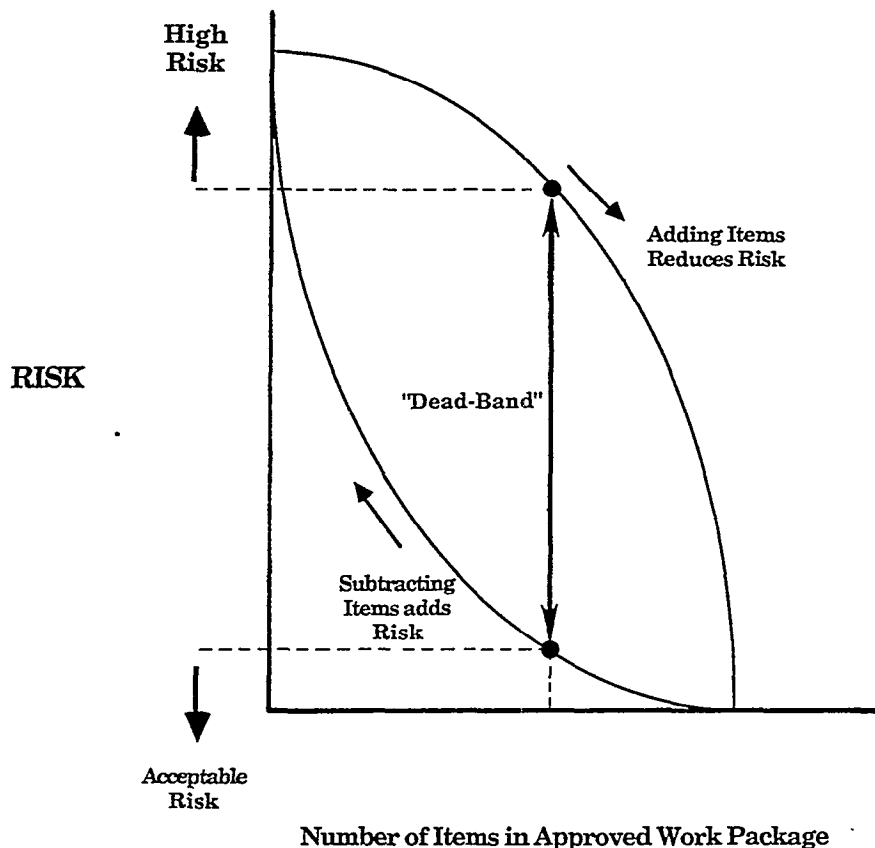


Figure 4
Risk Level Hysteresis Effect

with Category III (those repairs being accomplished by the shipyard line items with an overhaul impact is less than 5. mitigates. but does not eliminate, the risk associated with the 1,172 line items in Categories I and II. Additional trade-offs were required.

The risk assessment was undated to reflect decisions from the WDC. The 1,172 High Risk items were reviewed and reduced to a 337 line item list for further consideration (313 Category I and 24 Category II). This candidate list represents 113,292 mandays of growth reserve from Category I and 28,433 mandays of growth reserve from Category II which, based on the experiences on USS KIDD, can be anticipated. The anticipated growth reserve for both USS KIDD and USS CONSTELLATION represents 21 percent of the work authorized at the WDC. category III Acceptable Disk Candidates. of which their are 128, represents 3,543 mandays of work that could be deferred.

Specific actions taken on USS CONSTELLATION. The High Risk candidates list was reviewed to identify additional operational tests or detailed inspections to be conducted prior to the USS

CONSTELLATIONS arrival. Those items not rescreened to the shipyard required specific lay-up procedures and detailed Inactive Equipment Maintenance (IEM) instructions to detailed inspections to be conducted prior to the USS CONSTELLATION'S arrival. Those items not reassigned to the shipyard required specific lay-up procedures and detailed Inactive Equipment Maintenance (IEM) instructions to ensure no degradation occurred as a result of the industrial environment and length of the availability. Lavup and IEM for these items were Ship's Force reponsibility.

Second. those items for which operational testing was not feasible were reviewed jointly between NAVSEA and the shipyard for reconsideration and to eliminate potential problems in execution of the work.

Finally, the Category I and Category II High Risk mandays (141,725 mandavs) were used in calculating the Predicted End Cost of the availability.

CONCLUSIONS

The USS CONSTELLATION overhauling is fifty percent complete. To date over 20.00 mandays of high risk items have been reassigned to the shipyard. The ranking procedure for risk assessment continues to be used throughout the USS CONSTELLATION overhaul. for all new work requests. Work is accepted or rejected by the Shipyard based on the risk assessment criteria. This includes requests for Design investigations and Planners estimates. Those items not considered to be "High Risk" will be returned to the customer thus conserving Design and Planner resources. The ranking procedure is also used by the customer to prioritize the authorization of new work.

The risk assessment will be accomplished on all future assigned availabilities in order to assess the executability of the overhaul. to define which equipments should be overhauled and to determine the predicted end cost. The results will be monitored and work authorization measured against the risk assessment results.

The techniques used on USS CONSTELLATION provide a disciplined approach for the shipyard towards work package development and defining what repairs should be accomplished. It allows a reassessment of work package priorities and provides a level of confidence in meeting overhaul objectives. An analysis of this type also exposes the shipyard to a greater depth of knowledge and to the potential problems of the work package prior to the start of the availability.

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5. NAVSEADDET PERA cv. "Aircraft Carrier Material Condition and Readiness study Report"

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Modeling for Ship Design and Production

VIB-1

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Abbreviations

AMICE	ESPRIT Project 688 - Open System Architecture for CIM
CIM	Computer Integrated Manufacturing
ESPRIT	European Strategic Programme for Research and Development in Information Technology
GRAI	Groupe de Recherche en Automatisation Integrielle
IDEF	I*CAM (Integrated Computer Aided Manufacturing) Definition Language
IMPPACT	Integrated Modelling of Products and Processes using Advanced Computer Technology
IT	Information Technology
MARIN-ABC	Marine Industry Applications of Broadband Communication
MB/BB	Narrowband/Broadband
NEUTRABAS	Neutral Database for Complex Multifunctional Systems
NIDDESC	Navy Industry Digital Data Exchange Standardization Committee
NIAM	Nijssen Information Analysis Method
OoDB	Object oriented Database
OSA	Open System Architecture
RACE	Research and Development in Advanced Communication Technology in Europe
R&D	Research and Development
ROCOCO	Real Time Monitoring and Control of Construction Site Manufacturing
SQL	Structured Query Language
STEP	Standardization for the Exchange of Product Defining Data

ABSTRACT

The flexible operating and changing of the complex one-of-a-kind shipbuilding environment has to be based on adequate concepts and instruments to handle the related controlling, planning and implementation tasks. Product modeling defines the physical and application driven product related information. It is of basic importance to support this environment, especially the concurrent engineering functions, during the whole product life-cycle. Process modeling supports the implementation and operation of complex CIM (computer Integrated Manufacturing) oriented processes. In this paper some modeling applications within European shipbuilding R&D (research and development) projects will be highlighted from the viewpoint of an integrated product and process modeling approach. The following projects will be referenced:

- NEUTRABAS (Neutral Database for Complex Multifunctional Systems) explores a broad application field of product information for ship steel structure and outfitting systems;
- ROCOCO (Real Time Monitoring and Control of Construction Site Manufacturing) develops a CIM-application and demonstrates this application within the pipe outfitting environment of a ship berth construction site; and
- MARIN-ABC (Marine Industry Applications of Broadband Communication) demonstrates new applications and services in the maritime transportation business based on future mobile satellite networks.

INTRODUCTION

Information or system modeling of products and processes is becoming more and more important for planning, reconfiguration and operation of especially complex one-of-a-kind systems.

A model in the context of this paper gives an certain understanding of the real world in a descriptive form. Modeling is the task to

identify the universe of discourse;
abstract from the universe of discourse
towards an “academical” interpretation; and
formalize the universe of discourse towards
an unambiguous representation.

The universe of discourse within the real world is on one hand the product “ship” and on the other hand the process “ship production”(figure 1). The “ship” is defined as the physical product and the related information within the physical production process. The product has to be delivered within the **chain of order processing**. The process “ship production” is defined by the relevant order processing enterprize functions, the related tasks and physical production environment.

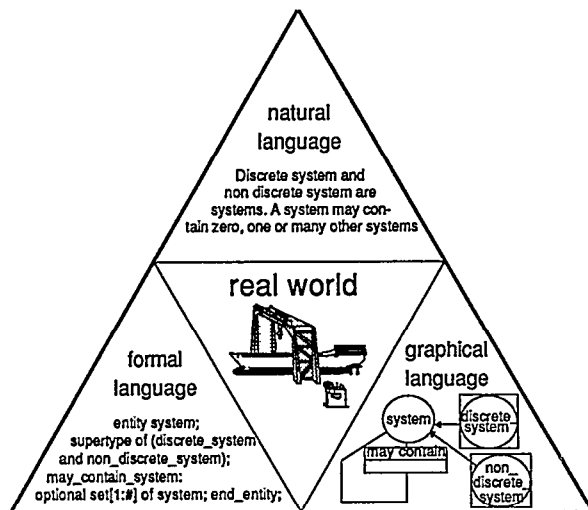


Figure 1: From Real World to Model

The product “ship” is described by information about its specific parts, systems and features. The information content of the model of the product “ship” is application driven. This means that the information needs of every application related to a task define the information content of the model.

The process “ship production” is described as a frozen dynamic (quasi static) system of activities. These activities within the production process are executed by applications. Many of these tasks can be IT-supported these are the ones faced at for the realization of CIM-concepts.

The universe of discourse in which the product and the production process are part of, is the life-cycle of ships in general. The life-cycle of the product “ship” is derived from the characteristics of process elements and the entities handled by the processes. The life-cycle builds the structured background for the modeling exercises presented in this paper. It starts with the sketching of the first idea and ends with the ship’s operation or its final wreckage. From a bird’s-eye view

- bid preparation,
- pre-design and design
- production coordination,
- production,
- operation, and
- (wreckage)

are the relevant steps within the life-cycle of ships.

The different reasons for a product model are derived from facts like support of information sharing, concurrent engineering, rapid calculations and development of alternatives. Starting from a first sketched idea of the future product, the amount of information for a product and its production increases steadily (figure 2). The ability to

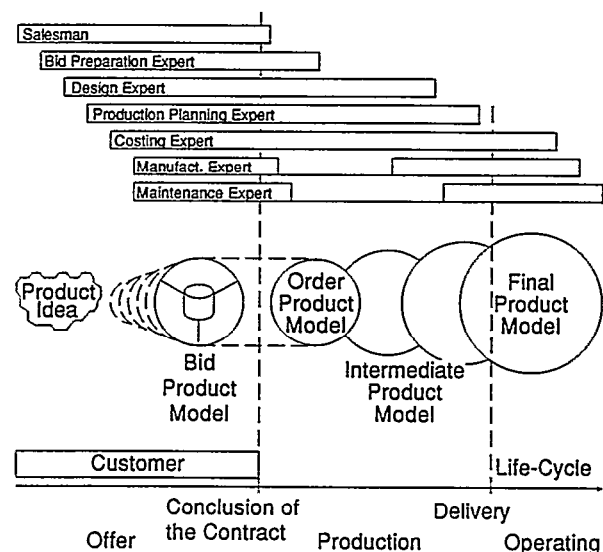


Figure 2: Evolution of Product Model

keep this information consistent and to support all related tasks in the development process with the correct data at the actual time, can be proved by a product model. A product model serves as a kernel to plug in all application programs and make use of the resulting synergy effects.

The development of a complex model as referred to in this paper is called product modeling. Maintaining the product model requires a sophisticated modeling technique to make changes and additions possible without redesigning the whole model and its related applications. The modeling methodology of the evolving standard STEP and its descriptive language EXPRESS is an approach able to fulfil the above mentioned requirement (1).

The necessity of process modeling approaches arises from the complexity and the flexibility requirements of the shipbuilding manufacturing process. The increasing degree of computer and communication technology support within industrial manufacturing environments in general leads to the need of a "structured concept or architecture" for CIM which is called "open system architecture" (2). The characteristic features of one-of-a-kind production - what shipbuilding obviously is - such as complexity and flexibility regarding the product and production, concurrent engineering constraints, and parallel manufacturing processes requires process models as an instrument of planning, reconfiguration and operation of the order processing and the corporate enterprise planning. In the context of this paper the tasks potentially supported by process modeling are:

- operation of complex CIM production systems;
- design, implementation, and adaption of CIM in production systems;
- cost-benefit analysis and techno-economic evaluation in the framework of plant layout (CIM-implementation); and
- marketability and risk assessment of future products and/or services to be provided.

MOTIVATION

The increasing complexity and individuality of products, especially focussed on capital goods, strengthens the importance of one-of-a-kind principles within the manufacturing industrial sector. Especially the European shipbuilding industry has focussed their product range on specialized and technically complex vessels such as container ships, passenger and multi-purpose ferries, specialized freighters and research vessels.

The economical constraints combined with strong market requirements of shortest delivery times have heavily influenced the manufacturing concepts of European shipbuilders. The hierarchical and modular organization of shipbuilding processes is developing more towards complex and parallel automated CIM-processes (figure 3). Due to the relatively small size and specialization of the European shipbuilding industry, one-of-a-kind as well as concurrent engineering principles have characterized the manufacturing environment, even before computer support has influenced the overall ship building processes.

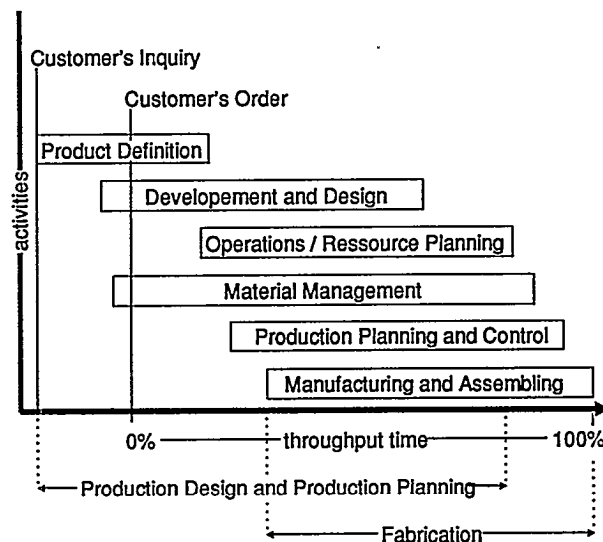


Figure 3:
Parallel Production Processes in Shipbuilding

Product complexity

High-tech (high-cost) carriers and specialized vessels - the characteristic product range of European shipbuilders - in general have complex, multifunctional product structures. Product complexity has following CIM-relevant impacts on engineering and production processes:

- sophisticated products demand multi-discipline engineering support;
- distributed knowledge and resources lead to distributed manufacturing concepts and a concurrent engineering approach; and
- design coordination as well as production coordination requires neutral product data exchange and product data sharing.

The inter-operability of functional ship systems such as steel structure, machinery, and electric is difficult to handle in daily business. If the interaction of system variables (e.g. engine performance versus vessel hydrodynamics) does not reach the planned result, a single person is almost unable to check all relations affected by such deviation. In this context distributed multifunctional design requires information structures and applied tools to follow and control all changes and inputs. Organizational functions during product design such as version control, approvals, and changes need to be based on the knowledge about the overall information flow within the engineering tasks. The need for knowledge about the 'where' and 'from' of the information makes the demand for an product of process model obvious.

Production complexity

The manufacturing of one-of-a-kind products such as ships is as a multidiscipline prefabrication and assembling process. Prefabrication, pre-assembly, pre-outfitting and outfitting work has to be scheduled and executed as parallel processes. Different kinds of resource organization (e.g. workshops, line-production, construction-site), different levels of automation (e.g. craftsmanship, conventional tooling machines, NC- and DNC-machines) and different disciplines of qualification make up the ship production process. Quality control of distributed prefabrication steps and coordination of work such as assembly and outfitting have to be based on an overall information and control structure. Following aspects of ship production must be mentioned:

- automated and integrated production, especially for one-of-a-kind products requires high performance data handling;
- distributed manufacturing and just-in-time supply require adequate production planning and control concepts; and
- shorter delivery time demands a higher parallelism of all steps for production including

concurrent quality control.

The requirements for implementing and adapting CIM-solutions to this one-of-a-kind production environments are in general anticipated in a broad field the manufacturing industry. From both the viewpoint of the IT users and the IT providing industry "generalized models are required to identify the principle components, processes, constraints and information sources to describe a manufacturing business processing towards CIM." (2)

Production flexibility

Due to the characteristics of European shipbuilders regarding of the product range, the value of flexibility regarding the production environment is of increasing importance. Changing product types, complexity and parallelism of order processing, short throughput times and fixed due dates lead to different aspects of flexibility reagrding the overall manufacturing process.

From the viewpoint of ship design, flexibility has to be understood as:

- developing design solutions depending on actual requested optimization criteria (costing, weight, noise, waste minimization, etc.) or any combination of those;
- developing different ship systems in parallel, their interrelations defined by a minimal functional description (concurrent engineering>);
- involving external engineering experts, subcontractors and/or services; and
- reacting to changes of the production environment.

From the viewpoint of production, flexibility means to be able to:

- build different kinds of products using the same or a changed production environment;
- cooperate within large varying consortia of subcontractors and suppliers;
- react to lack of capacities in different disciplines and departments;
- deal with non-pre-defined order flows (concurrent engineering);
- satisfy different customers' quality standards under economic constraints.

Production control must be handled on the basis of actual economic optimization criteria (e.g. costs,

due dates, consumption of man-hours) and external or internal unforeseen events like unavailability of resources, delayed sub-delivery dates, delayed due dates. The complex production scenario in ship-building with high probability of unforeseen events in every production phase must be flexible to react immediately to actual control decisions. This capability must be based on detailed monitoring of the actual production progress as well as on the actual capacity load of resources. This has to be based also on descriptive functional and operational models of production processes and multi-order handling.

Modeling Requirements

The described features of complexity and flexibility, which provide both a global and a detailed understanding of the manufacturing systems behavior and controlling mechanisms, as of the product to be manufactured. With regard to the production and design management tasks the value of modeling instruments, techniques and approaches must be evaluated under the following aspects:

- Configuration or change of the production environment must be integrated with instruments that operate and control the production and design process.
- To be able to handle actual and unambiguous product information is a basic requirement for flexible process management and control, especially of the concurrent engineering process.
- The functionality of process elements (even the CIM elements) as well as the product requirements have to be understandable not only for the engineers or the production and design managers, but also from the perspective of the shopfloor workers.

This viewpoint has been the basis for the modeling approaches and exercises of the following examples. The implementation of CIM elements in the manufacturing environment, as well as the handling and control tasks of distributed multi-supplier organizations has to be conceptually supported and developed by the production and production management experts. Even the introduction of advanced services, based on enterprise internal knowledge about the complex products, has to be based on the involvement of the service providers as well as of the end users.

PRODUCT MODELING

The product model described below is the result of the ESPRIT project NEUTRABAS. The development of the Product Model SHIP is based on the product modeling methodology of the evolving ISO Standard STEP. Information Model in this context means the description of the real world in a way which is independent from any implementation restrictions.

The NEUTRABAS Project did benefit much from the exchange of ideas and the cooperation with the NIDDESC project group. NIDDESC was initiated before NEUTRABAS and has contributed valuable documents to the ISO STEP committee. (3), (4). NEUTRABAS has incorporated NIDDESC concepts and is working on complementary areas of the product life cycle.

Model Structure

The NEUTRABAS Product Model aims to cover the whole life cycle of a ship (10). For the time being two main models are defined to describe the "Object Ship:" the Ship Structural Model and the Ship Outfitting Information Model. Beside these there are the Ship Global Information Model and the Ship Spatial Arrangement Model. These Models have to be integrated and combined with the ship Reference Model.

Ship Global Information Model (SGIM):

SGIM contains information not only about the ships main dimensions, but also the information describing the performance of the ship such as speed, tank capacity, number of containers, etc.

Ship Spatial Arrangement Information Model (SSAIM):

SSAIM covers the information about the room arrangement, how surfaces and volumes define the subdivision of the ship. These subdivisions are: zones, compartments, major surfaces, their boundaries, contents and loads, and their related attributes.

Ship Structural Information Model (SSIM):

SSIM describes the information related to the design and production process of the ship steel structure. At the first level the shell plating associated with the major surfaces, including the partition into plates and its relation to internal

structures, are outlined. At the second level the stiffening and connection between elements, including standard shapes, their arrangement and connection with plates, are described. At the third level apertures and other inconsistencies including those for man access, circulation of fluids and passage for duct-, pipe-, and cable-work are defined.

Ship C&fitting Information Model (SOIM):

SOIM defines everything within the steel envelope. Examples are machinery, cargo handling systems, accommodation, and electronic equipment. To present all information about these different systems in a neutral way, the model must be independent of any specific enterprise's product structure and at the same time complete and general enough.

With the aim of an integrated model, the development of application driven partial models was started. The view on a ship and/or part of a ship changes over time. It starts with the viewpoint of the staff responsible for the contract, then passes to a shipbuilding engineer responsible for the design of that system, then to the production engineer, and so on, according to the procedures necessary to make an idea a product. The last view in this chain is the view of the owner who operates the ship and tries to earn money with it.

It is one of the main requirements for a product model to handle all these different views.

The Outfitting Functional Model (which is a part of the SOIM) serves as an example for the entire NEUTRABAS model. It contains the information necessary for the contract and functional design. It will be described later in more detail. Besides the mentioned NEUTRABAS models, STEP provides resource models such as geometry, topology, material, etc. One of the crucial tasks still to be performed is the integration of these different models. Within NEUTRABAS different integration strategies have been discussed. The most challenging one is shown in figure 4. The approach under consideration is the integration via one general model relating the partial and resource models in a flexible and open manner. This general model provides all information necessary to derive all key entities of the partial submodels via multiple inheritance. This approach is also used within the IMPACT project (8).

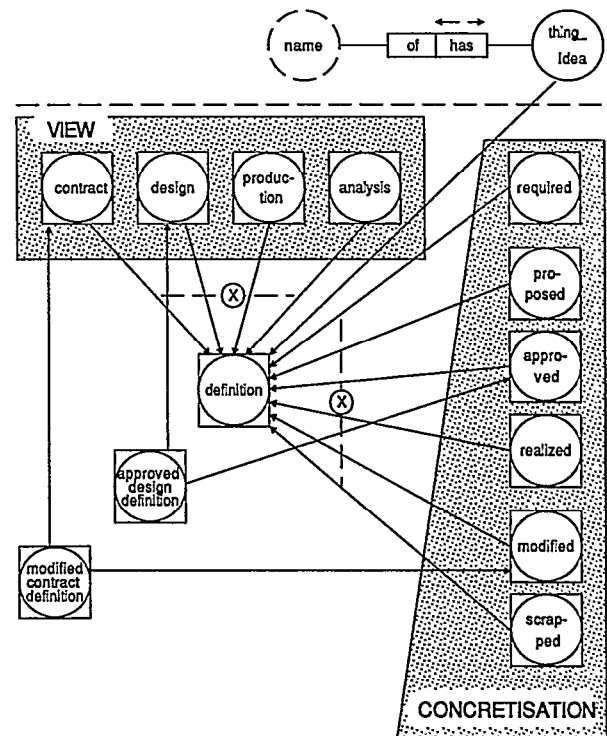


Figure 4: High Level Integrated Model

Modeling Methodology

The development of the model follows the STEP idea to provide a common mechanism for representing Product Model Information throughout the life cycle of a product, independent of any software that may be used to process it. "The definitions given within these models are independent of the many possible ways in which the related data might be implemented." (5)

Based on an entity pool and attribute list which arose from a questionnaire activity of the NEUTRABAS partners, a graphical method was used to illustrate the relationship of entities. Within the STEP community the use of IDEF1x and NIAM is common practice. NEUTRABAS decided to use NIAM because

- 1) its approach is more implementation independent than that of IDEF1x;
- 2) it is used by the NIDDESC group; and
- 3) of its readability even for those who are not familiar with semantic modeling. The point refers to the main benefit of the graphical representation and the illustration of entities and their relations as a basis for the discussion with "experts".

The author-reader cycle of modelers and experts, required some extensions of the NIAM to distinguish between relations which are approved or still under discussion. There are also NIAM extensions which take into account the complexity of the multifunctional model, in particular mechanisms to reference from an incomplete description to entity descriptions in other sub-models. In the discussion of modelers and experts the most crucial difficulty was in combining the generic approach of the model with the very precise and specialized understanding of the experts (figure 5). To overcome these problems “hand-made” population of a model with “real world” examples turned out to serve as helpful exercises.

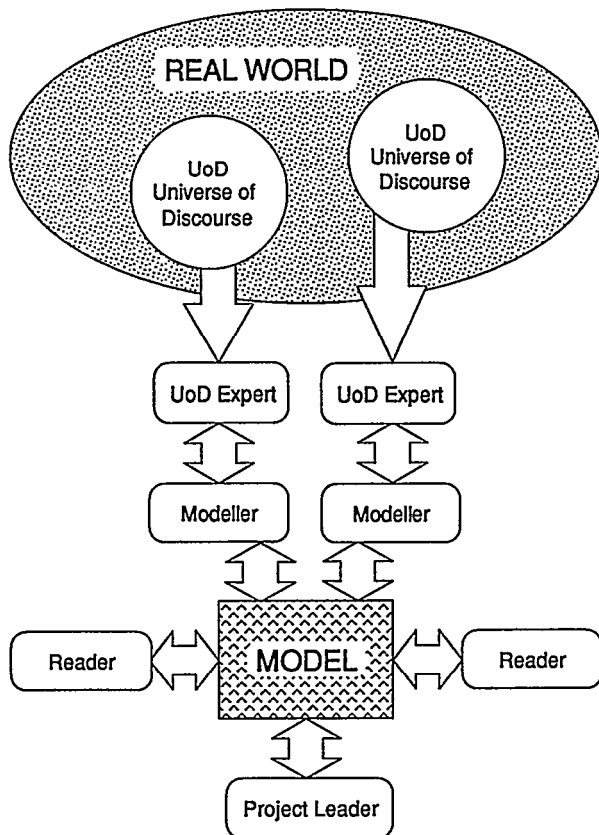


Figure 5:
From Expert Knowledge to an Information Model
The next step following the definition of the graphical model description is to derive a semantically irreducible definition of the model based on the NIAM diagrams with the help of a modeling language. Guidelines have been developed to streamline and standardize the process of mapping graphical model content into a (EXPRESS) language model. Figure 6 shows in selection some of these mapping rules from NIAM to EXPRESS (9). To handle this, first a pseudo code is to be created. The pseudo code contains the entity name, types

and subtypes, their attributes, restrictions and rules, and of course, the definition in natural language.

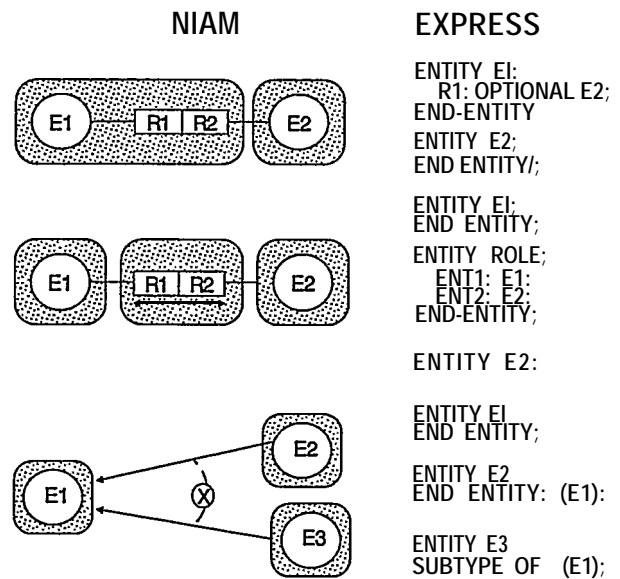


Figure 6: From NIAM to EXPRESS

Following this EXPRESS code is to be generated. EXPRESS is the information definition language designed for the requirements of information modeling within the context of STEP and is going to be standardized by ISO.

Due to the lack of sufficient tools the above-mentioned process is more or less hand-made, i.e. with the help of drafting tools, databases and word processors (figure 7).

EXPRESS then can be checked for its syntactical correctness using one of several available EXPRESS parsers (6). Most of them provide only syntactical check based on EXPRESS versions more or less behind the actual language definition. Within NEUTRABAS a data dictionary was developed to serve as a basis for different modules to handle the EXPRESS code and the information behind it to fulfil tasks like EXPRESS to SQL or EXPRESS to OODB mapping, etc. The development of integrated tools to support the modeling process, considering the above mentioned problems and required capabilities as described above, is an ongoing process worldwide.

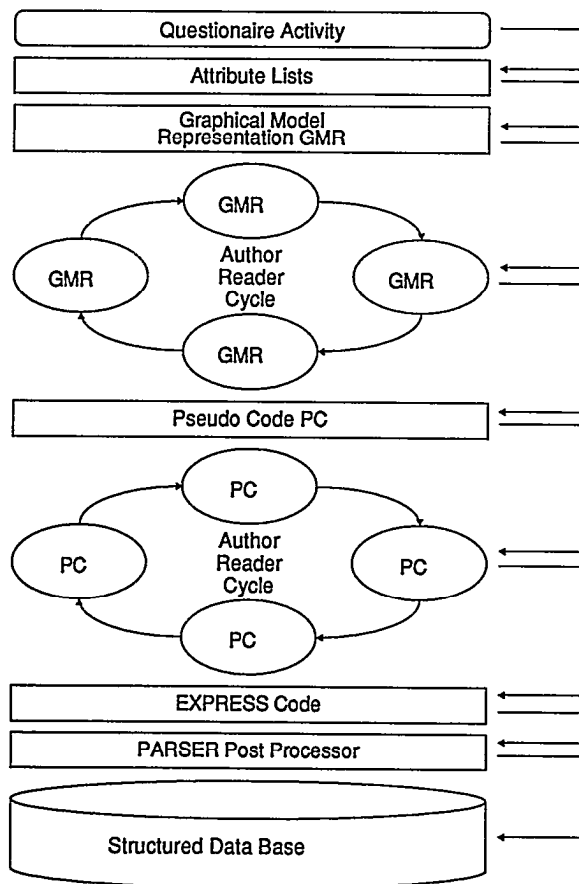


Figure 7: From UoD to Database

Functional Model

Within NEUTRABAS a new type of product modeling was worked out. It was named Functional Model and it deals with the description of what a product does or in other words what function it can perform. The necessity for such a model was obvious for documenting the creation of any system within a ship or within any other complex product. In spring 1991 a "Functional Model" working group was established in the STEP arena trying to handle this problem area.

During the design process, different designers are working on the same ship-outfitting system. Each of these designers is responsible for a certain functionality of the system. If the proposed results are conflicting, they have to be checked against the system requirements and a coordinated solution has to be found. This new solution must meet the requirements as well as perform the different functions of the system. To reflect this information in a product model is the purpose, the functional model is used for.

In reality each system plays different roles to satisfy different functions. One approach to handle the problem is well known as Taylorism but it will fail in this case. But the interoperability between the systems and their functions allows no isolated problem solving strategy. To handle the multifunctionality of a system which contains other multifunctional systems in one product model, an entirely integrated approach is needed. This may end with a redundant data structure which has to be controlled somehow. For example: a pump plays a role in the distribution system. It pumps a certain amount of fluid in a certain time interval up to a certain level. The same pump plays the role of an energy consumer in the electrical system as well as playing the role of an agent in a vibration calculation, and so on. It is conceivable that this pump could also play some more roles within the system "Ship" where it is installed. The NEUTRABAS outfitting model contains various functional systems e.g. distribution, containment, connection, control, fixing, heating, information, transformation, transportation, system.

The basic entity in the NEUTRABAS ship outfitting functional model is "system". It was chosen to describe the reason for the existence of each product within its environment. Thus a set of components joined to play a certain role together may be called a system. For the decomposition of a system into its components a recursive structure is used so that a system component can act as a system in its own right. This implies that one system or system component has different roles in different contexts, and/or different functions in different contexts. This is called multifunctionality.

This methodology serves as a basis for the definition of attributes required to carry out and accomplish the different engineering tasks. The calculations necessary for sizing of system can be associated with the systems components. Due to the associations of a system with its environment, the cross reference effects is obvious.

The modelers intention is to configure the model in such a way as to foresee the possibility of checking the model against rules and specifications. This should include requirement lists, owner specifications, classification rules and national regulations. For the time being the computer aided applications in these areas are still missing, or they exist only in a research environment. But it is expected that when such models exist, the usability of this information for testing and checking will increase immediately.

PROCESS MODELING

Process modeling discussed in this paper is the description of business activities in order to achieve specific technical or - more general - economical enterprise objectives. The formal components, rules and constructs to describe a problem oriented view on business activities as well as the information structure behind is the background of the process modelling exercise. The exemplarily cases will describe process modeling as a supporting instrument for introducing computer technology in order to achieve technical or economical enterprise objectives. This regards on one hand the adaption of a shopfloor monitoring and control system within a shipyard outfitting environment and, on the other hand mobile satellite services as a communication platform for maintenance and repair support in ship operation. The one-of-a-kind characteristic of the product was the driving force for investigating in modeling applications in both R&D projects. The applied modeling methodologies and instruments are referred to in basic projects within the ESPRIT program.

A basic R&D investigation in the development of standardized architectural frameworks for computer application in industrial environments was established with the ESPRIT project CIM-OSA (ESPRIT 688: Computer Integrated Manufacturing - Open **System Architecture**). The CIM-OSA consortium AMICE defines its modeling objectives from the viewpoint of both the IT and applying industries. It formulates the objectives as, "to define a set of concepts and rules to facilitate the building," (planning, implementation, modification, extension and operating) of future CIM systems. A three-dimensional framework of architectural levels, modeling levels and views has been established to describe business processes (figure 8). "Generalized models are required to identify the principle components, processes, constraints and information sources to describe a manufacturing business processing towards CIM. The generalized models then need to be made specific by including aspects from particular manufacturing segmentations. Such a structured concept or architecture is called open system architecture (OSA)."(2)

A broad approach to define characteristics of one-of-a-kind production is introduced in the FOF (Factory of the Future) project (Project Towards an Integrated Theory of Design, Production and Production Management of Complex One-of-a-Kind Products in the Factory of the Future). The "human

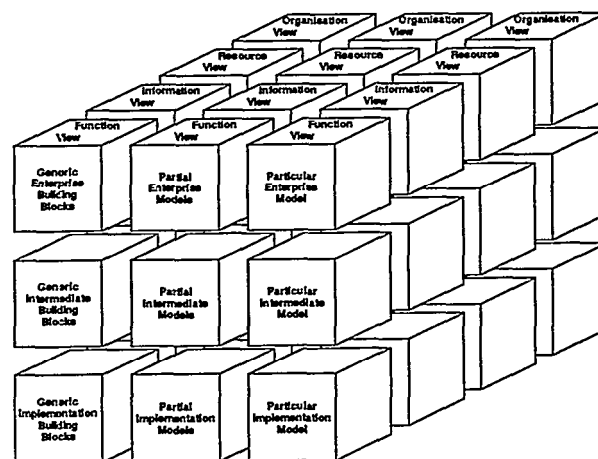


Figure 8: CIM OSA Modeling Framework

view" has been established as the basis of an additional integrative model. This view has been introduced with the assessment "that the crucial point was, that (in general) the IT approach (the approach of introducing information technology) was focussed to enlarge the information and knowledge-base for managers. This improves the ability of control for the managers but still excludes the creativity, skills, involvement and engagement of the direct production workers." The breakdown of various aspects of one-of-a-kind production can be summarized according to the FOF project as

- operations research and cybernetics,
- human oriented,
- communication oriented,
- databases,
- functional,
- organizational, and
- economical.

The following described applications of modeling methodologies and techniques are referring to European R&D investigations in the field of CIM-implementation at shipyards and introduction of mobile communication applications for the maritime industry.

Implementation of CIM in One-of-a-Kind Production

The economic challenge to adopt modern technology to complex manufacturing processes demands the thorough knowledge of features, behavior and interrelations of process elements. The definition of requirements for the adaptation and implementation of CIM elements needs to be based on the problem

oriented description of the system environment in question.

The ROCOCO project (ESPRIT project 2436: Real time monitoring and control of construction site manufacturing) deals with implementing a shop-floor control solution into shipyard construction (7). The background description of the behavior and control mechanisms of outfitting processes has been worked out for an example shipyard. The developed reference architecture is general to other shipyards and - what is much more essential - also comparable to heavy engineering manufacturing systems. The reference model focusses on the implementation of a LSC (local shop computer) workstation into a pipe fitter's working environment. The LSC workstation is connected to a data capturing infrastructure as well as to the central engineering computer systems.

In order to reach a wide anticipation of the described modeling exercise, the main objectives of the ROCOCO modeling approach were:

- modularity;
- generality;
- extendability; and
- to be adequate for implementation,

which are in line with the CM-OSA objectives.

The ROCOCO project objectives require that the modeling approach must generate a generic reference architecture for different shopfloor applications. Similiar workshops at a shipyard (e.g. HVAC prefabrication) can - from the view of control behavior - be supported by the same conceptual LSC components. In general the PPC (production Planning and control) point of view has mainly influenced the selection of the modeling methodologies. The adopted GRAI and IDefO methods have been selected in order to follow the CIM-OSA objectives as far as possible.

The decision for using two different modeling methodologies was driven by the different characteristics of the two major implementation worlds. The physical production process (e.g. pipe prefabrication, staging, installation) contains the material tracking elements of the business processes. The complementary management world acts as the source for monitoring data and controlling events. Its functionality is characterized by the material flow, organization of work, machinery equipment and labor. Different work trades are similar, or more or less comparable in their controlling behavior within the business process. The production management process (e.g. design, stock

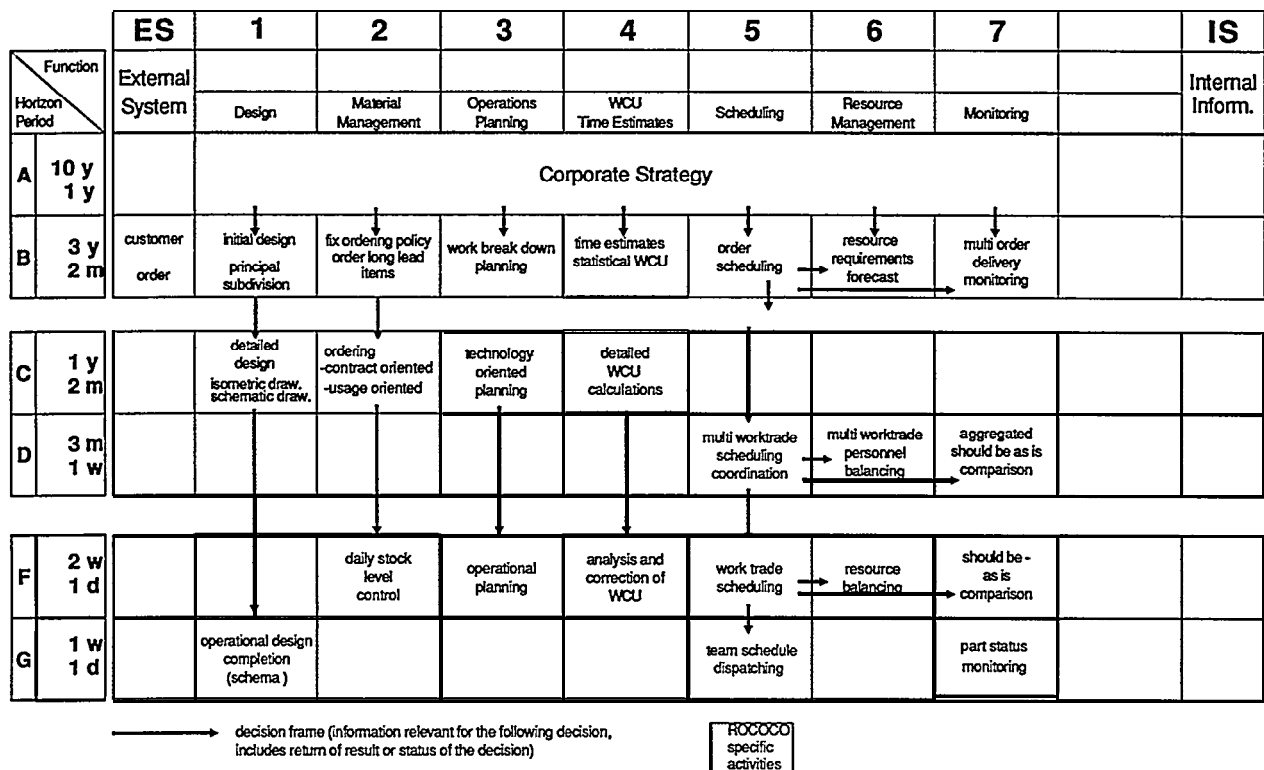


Figure 9: GRAI - Grid Activities

keeping, PPC) is characterised by the event driven mechanisms of decision making and information handling. A limited group of centralized enterprise functions has to specify, plan, trigger and control an extendable number of decentralized worktrades or shopfloor departments (figure 9). The GRAI methodology differentiates for every enterprise activity specific strategic, tactical or operational levels. Those enterprise activities relevant for the LSC application are mainly allocated at the operational level; for interconnecting the relevant planning and scheduling tasks enterprise activities from the tactical level are involved. In order to get a controllable and effective management structure, different connected decentralized workshops have similar interconnections and feedbacks to the central order management system.

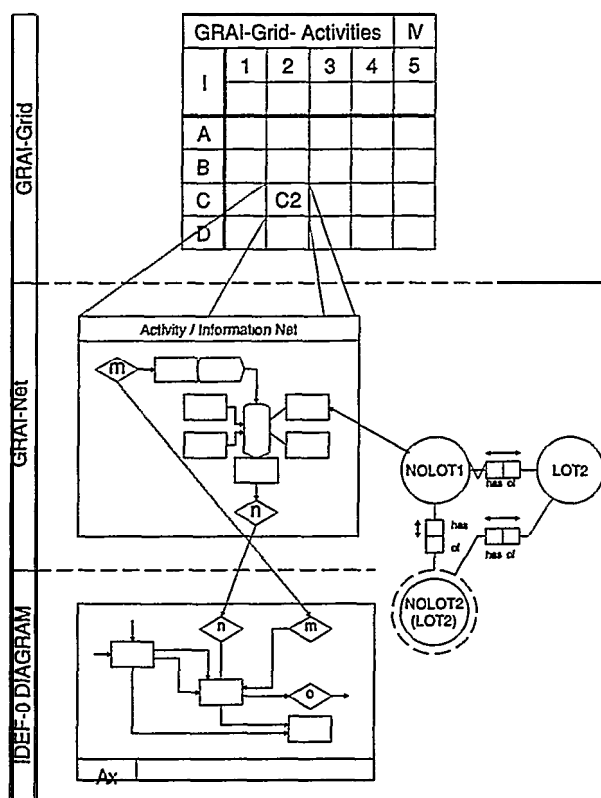


Figure 10: GRAI - IDEFO - NIAM Interconnection

In addition to the two-fold functional description of the business processes, NIAM as a data modeling language was used. The NIAM descriptions were methodically connected to the integrated GRAI and IDefO format of the process description (Figure 10). The connection and integration of the three adopted methodologies has to be used as an implementation guideline for the developed LSC application systems. The guideline has to be generic for different types of construction site manufacturing within the

heavy engineering industrial sector. The integrated methodological approach has to end up in generic descriptive elements (generic building blocks) which, by following the CIM-OSA objectives, is a step towards the Generic Building Blocks within the CIM-OSA Modeling Framework (see also figure 8). The ROCOCO specific objective to adopt this integrated approach on a concrete level is to get a well defined specification of the controlling and controlled processes on the one hand, and of the applied CIM-solution on the other hand.

Communication Applications in Ship Operation

The advanced potential of IT.-applications is in the complex context of the extended enterprise logistics. Manufacturers, suppliers, distributors and operators are closely related to the product. In this context the economic importance of logistics and services based on worldwide communication infrastructure arises. The ability to provide consultancy, expertise and assistance to ships at sea is examined within the MARIN-ABC (RACE project 1062: Marine Industry Applications of Broadband Communication) project. This project demonstrates a pilot application of integrated NB/BB (narrowband/broadband) interconnection of shorebased and mobile - ship located - communication partners. It is assessed that competent support for maintenance and repair tasks, multi-media information services can solve the spontaneous challenges of economic ship operation. The integrated flexible use of video, audio, pictures and data (multi-media) provide most of "human comparable" communication features. The adequate implementation of end user equipment and services must ensure the most effective support of a spontaneous problem situation.

The modeling of the communication infrastructures in relation to the application services and end users' activities (within their business environment) describes different communication scenarios. The modeling exercise specifies the value of communication applications from the viewpoint of:

- application functions within ship operation,
- specification of technical requirements,
- marketability assessment of mobile communication services,
- implementation strategies and cross-impacts of introducing mobile communication to the european market, and

- scriptbook of an advertising application scenario to be realized within a video clip.

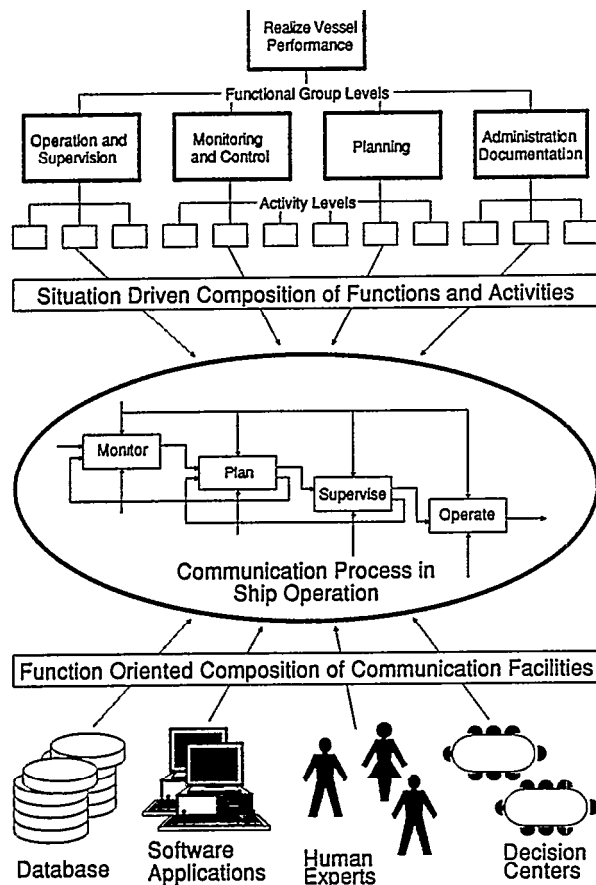


Figure 11: Function Oriented Composition of Communication Facilities

In accordance with the CIM-OSA approach, four essential views have been defined:

- 1) The object view decomposes the onboard functional and technical systems down to a significant level to handle maintenance and repair tasks.
- 2) The functional view structures onboard and shorebased activities (application functions) related to maintenance and repair tasks, such as expert supervision, tutorial assistance.
- 3) The organization view describes the onboard and shorebased local allocation and distribution of responsibility of tasks, such as technical superintendency of a shipping company.
- 4) The resource view deals with the IT application and communication interfaces, networks

and services which utilize the diverse tasks within ship operation on board, and the shore based consultancies.

The modeling exercise ends up in a reference architecture of user applications of integrated NB/BB communication in the field of ship operation (figure 11). Database implementation of an extension of the IdefO methodology leads to an estimation of quantified communication demands. Based on a specific application scenario described from the mentioned four views, transmission rates, frequency of use and transmitted information rates can be estimated (figure 12).

A techno-economic evaluation of these communication applications and network configuration from the view of the end users results in the providing of services and networks. This exercise of pre-com

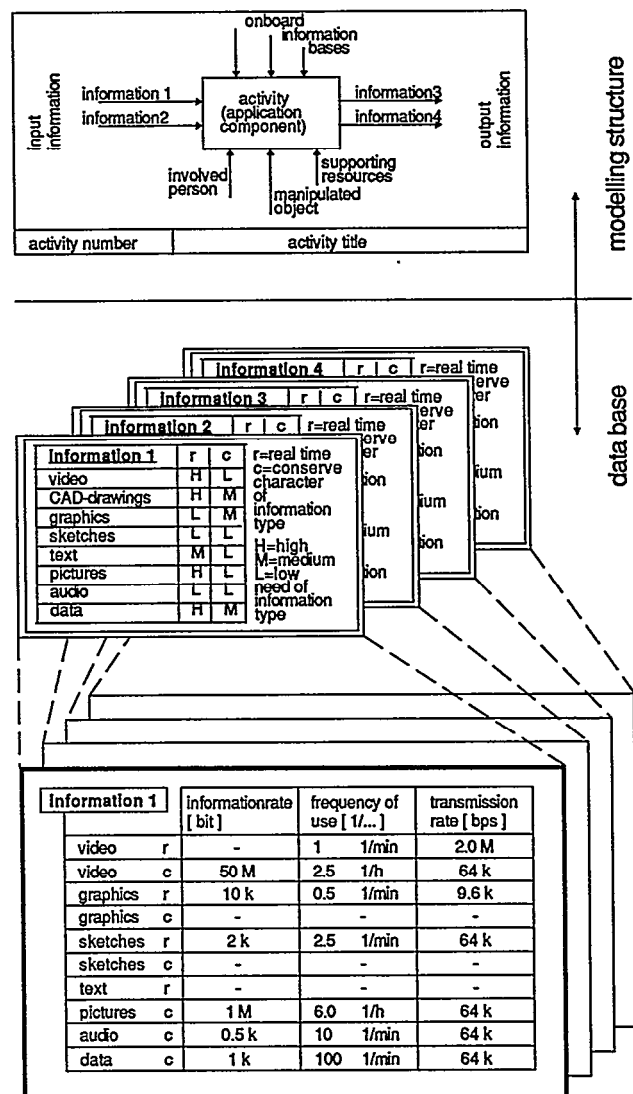


Figure 12: Database Enhancement of Communication Model

petitive assessment of marketability potential of mobile NB/BB communication in the context of the RACE programme opens the market for competent services of the maritime ship-building and operating industry. The challenge of especially the shipyards - in close cooperation with the shipping industry - is to provide additional services based on the deep knowledge, expertise, information about the complex multi functional products they build.

Modeling in the context of the MARIN-ABC project has the task to find, to describe and to evaluate useful applications for a technology (in this case the integrated NB/BB communication) which is planned to be available in the near future.

FUTURE OUTLOOK

In the far and near past in shipbuilding history, the overall manufacturing process developed from towards scenarios of distributed competence, resources and performance. The shipyard itself is, in this scenario of distributed subcontracting and supplier cooperations, in the position of the central project manager.

The classical process chain ship manufacturing such as pre-design, design, operations planning, and starts from developing the first product idea and ends up with the rough job to fit and outfit the final product. The demands for heavy and expensive resources such as building docks, gantry cranes and steel hull fabrications facilities even today give the shipyard the position of the assembly and outfitting center for the complete ship. A complex distributed multi-supplier and multi-sub-contractor organization is grouped around the "central" shipyard. An increasing number of specialized tasks is distributed to these companies competent on their specific domain. The shipyard as the central project manager has the difficult and important task of planning and controlling such complex multi-partner cooperations. In future, shipowners, yards, classification societies, suppliers, and sub-contractors are active partners in ship manufacturing and ship operation. Powerful communication networks and applications are the technical background for the integrated maritime business of the future.

The challenging task for the future is, according to the referring European R&D programs, to realize the implementation of CIM to one-of-a-kind pro-

duction. As a concrete representative of this kind of production the European shipbuilding industry has to focus on their capability to develop highly specialized and high quality products under manufacturing conditions which ensure economic and effective order processing. Mapping these main objectives on the capability of computer applications in general the economical trends of introducing CIM has to be seen in:

- increasing flexibility and effectivity of automated pre-fabrication;
- increasing effectivity of (especially outfitting) work by adequate planning and control instruments;
- exploiting the benefits of overall availability of product and production information;
- effective operation of complex distributed cooperations in manufacturing and concurrent engineering scenarios;
- providing competent services and logistics based on product life-cycle information.

Getting the competence and experience to handle complex distributed design and production systems is the key to exploiting synergy effects of CIM in distributed one-of-a-kind production. The complexity of those distributed manufacturing scenarios requires the adoption of the multi-view modeling approach in order to develop applicable CIM-concepts. The requirements for a supporting modeling approach towards implementation of CIM for these kinds of complex scenarios can be summarized by the keywords integration and distribution.

The integration of manufacturing applications with relevance for CIM has to be based on highest availability of product relevant information and highest performance of adequate product information exchange. The product modeling exercise, ending up in neutral standardized definitions for product defining data, has to consider the interests of maritime industrial users. Even the introduction of product modeling methodologies and techniques and the guarantee of a wide anticipation of modeling is of strategic relevance for CIM-implementation in shipbuilding.

The handling of distributed tasks, the managerial and organizational cross-impacts of companies interests and competence is based on communication between computer applications as well as between human users. Modeling the functional interconnections of tasks is the starting point for

planning, configuration and handling of distributed manufacturing cooperations supported by CIM-elements. The interconnections of tasks and the cross-impacts of goals and sub-goals needs to be modeled on an abstract level in order to ensure the most economic configuration for each project objectives.

Regarding the process chain of manufacturing, in the future the design and sustaining engineering work, as well as the modular pre-fabrication of machinery and outfitting components will be distributed more to subcontractors. In this regard, the distributed tasks have to be specified, planned and controlled based on additional descriptive modeling elements. The functional and managerial interconnections of distributed sub-contracted engineering activities must be organized. Technically it must be agreed upon information exchange and documentation formats, terms of responsibility and delivery. In general, the integration of the process chain of distributed manufacturing scenarios has to be supported by interfaces which consider both the technical requirements as well as the economic and organization objectives. The specification and realization of these interconnections for the benefit of all partners in such cooperation must be strongly supported by both product and process modeling techniques.

Complex distributed cooperations lead to new requirements for the order chain of enterprise functions (acquisitions, tendering, cost-calculation and control, production planning and control). Shortest and reliable due dates, and most economical and effective achievement of manufacturing sub-goals directly requires the optimal operation of complex concurrent engineering scenarios. As the shipyard has to manage this scenario, the importance of multi-level planning and controlling techniques, with appropriate enhanced features arises. Modeling the behavior and mechanisms of changing order related cooperations is the starting point to realize and operate the future complex and distributed order processing.

Enhancing the described modeling exercises of the different CIM relevant projects in this paper, following open subjects have to be named:

- generic CIM element database and configuration support;
- flexible production environment configuration support according to product requirements;

- integrated techno-economic evaluation of CIM-systems;
- open inter- and intra-enterprise information exchange and communication; and
- open information infrastructure for plug-in applications.

The modeling methodologies and techniques to support on the one hand the distribution of work to complex consortia and on the other the integration of applications for different competent tasks need to be handled as an integrated set of instruments for planning, configuring and operating future CIM-production in shipbuilding. Realistic economic goals of concurrent engineering scenarios can not be reached without concentrating both on integration and distribution aspects of CIM in one-of-a-kind production. Therefore the deviating ways of following the product or process modelling approach has to be integrated to a future approach of product and process modelling.

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Developing and Using an Expert System for Planning the Production of Structural Piece-Parts

VIB-2

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ABSTRACT

This paper presents an example of how expert systems can be developed and used for planning structural piece-part production. First, expert systems are briefly and generically described. Then the production processes within a shipyard-like structural piece-part production facility are defined within an expert system "shell"; i.e., the "objects", "attributes", and "rules" describing the production process are established and explained. Then various structural piece-parts are described to the system and the system identifies the required production processes for each described part. The inference process underlying the identification of these processes is described for each of these parts. Finally, potential applications of expert systems to other areas of shipbuilding operations are discussed.

EXPERT SYSTEMS, A GENERAL DESCRIPTION

The intent of this paper is to build on previous presentations on the application of expert systems in a shipbuilding environment (1)(2) by providing an actual example of a potential expert system application to shipbuilding. But first, a general overview of expert systems is in order.

Expert systems have evolved from within the "artificial intelligence" area of computer science. As the name implies, the intent of an expert system is to emulate the decision-making process of an "expert" within a specific domain, or area of interest. In this way, expert systems differ from traditional computer applications as they lend themselves more toward the resolution of problems with uncertainties in supporting data, and/or with large numbers of exceptions and potential options which would make it virtually impossible to derive singular "optimum" solutions. An expert system is "rule driven" meaning that a "good" solution is derived based on rules and an associated decision-making hierarchy which have been provided by an "expert".

Expert system software tools, called "shells," are created in languages such as "C," but have evolved to the point where users need not be familiar with underlying code. Users are only required to be familiar with an overlying, and fairly straightforward information format and English syntax to describe their domains of interest. Note that the author is not a computer scientist, nor had he any user experience with expert systems until October, 1990.

The representation of a particular domain within an expert system is called a knowledgebase. A knowledgebase is made up of objects, object attributes, attribute values rules and m. An object is any group of information which has meaning. An object can have a name like "ship" and can also have attributes such as "length", "draft", etc. Each attribute can in turn have a value, such as "draft=10 m (33ft)."

Rules are developed to describe how the objects within the domain interrelate. These rules are generally in an "if...then...else..." type of format. For example, a rule could be written to determine which drydock a particular ship can use, as follows: If ship draft ≥ 10 m (33 ft) then drydock number is 2. This example assumes that another object called "drydock" has also been defined.

Goals simply establish which object attributes the system is to solve for. In the example above, the goal would be to solve for the object attribute "drydock number."

Modern expert system shells can automatically generate objects and attributes from rules as these rules are defined in the knowledgebase, or the function of object and attribute definition can be independent of rule definition.

A knowledgebase is developed through "knowledge acquisition" and "knowledge engineering". "Knowledge acquisition" is the process of identifying the objects, attributes, values, and rules that represent a domain, in essence identifying as accurately as possible how the domain of interest really works. This is done by interviewing, video taping, and working with the real experts within the working domain. The process of assimilating this domain information

into a system-usable form, and actually creating the knowledgebase is called “knowledge engineering”.

Expert systems become smarter as the domain is defined with greater accuracy and in more detail within the knowledgebase. For example, the rule that was written earlier for determining which drydock a ship can use becomes smarter with the addition of more domain information: If ship draft ≥ 10 m (33 ft) and ship length ≤ 200 m (656 ft) then drydock number is 2. In this case, another dimensional limitation of the domain has been defined, and the expert system using this rule can infer a smarter solution than it could have using the rule as it was previously written.

AN EXAMPLE SHIPYARD DOMAIN: STRUCTURAL PIECE-PART PRODUCTION

When developing an expert system, it is very important to establish boundaries which limit the scope of knowledgebase development work to a well defined domain. For the purposes of presenting an understandable example within the limitations of this paper, the example presented will be limited to structural piece-part production excluding surface preparation and coating processes, lay-off processes, and assembly processes (the production of “superparts,” which are made up of multiple pieces, is not considered in this example). The fabrication facility and processes in this example are intended to be generic and capable of producing approximately fifty-thousand tons of structural piece parts annually when utilized at a high level.

Definition of Production Process Objects, Attributes, and Attribute Values

Following is a list of the structural piece-part production processes that have been defined as objects in the knowledgebase. The layout of the example facility is shown in Figure 1.

Burning Processes:

- . Flame Planer 1, FP1
- . Flame Planer 2, FP2
- . N/C 2-Axis, BR1
- . N/C Plasma, BR2

Press Processes:

- . Brake Press, PR1
- . 1500 Ton Press, PR2
- . 37.5 Ton Press, PR3
- . 600 Ton Press, PR4
- . Frame Bender, PR5
- . 250 Ton Press, PR6
- . 60 Ton Cold Press, PR7

Roll Processes:

- . 2000 Ton Roll, RL1
- . 12' Roll, RL2

Planers:

- . 40' Edge Planer, PL1

Drills:

- . plate Drill, DR1
- . Shape Drill, DR2

Saws:

- . Band Saw, SW1
- . Hydraulic Band Saw, SW2
- . Contour Band Saw, SW3

Shears:

- . Shear, SH1
- . 100 Ton Punch, SH2

The generic processes of “cut”, “edge prep”, and “form” have also been defined within the example knowledgebase. These generic processes and their associated attributes can be inherited by the specific processes listed above based on their capabilities. For instance, the N/C Plasma process can both cut and edge prep. Therefore, this process can inherit the attributes of these two generic processes, and then values relating specifically to the N/C plasma process can be defined for these attributes. Following is a list of the attributes associated with each generic process. For a detailed list of specific process attribute values which define the capabilities of each specific process, refer to the complete object and attribute listing in Appendix A.

Cut:

- . # of axes
- . # of master cut tools
- . # of slave cut tools
- . angle cut maximum
- . automation level
- . cut accuracy
- . cut configuration
- . cut length maximum
- . cut location
- . cut part depth maximum
- . cut part length maximum
- . cut part width maximum
- . cut routing code
- . hole diameter maximum
- . mat'l cut thickness maximum

Edge Prep:

- . bevel accuracy
- . bevel configuration
- . bevel degrees maximum
- . edge prep length maximum
- . edge prep location
- . edge prep part depth maximum
- . edge prep part length maximum
- . edge prep part width maximum
- . edge prep routing code
- . edge prep thickness maximum

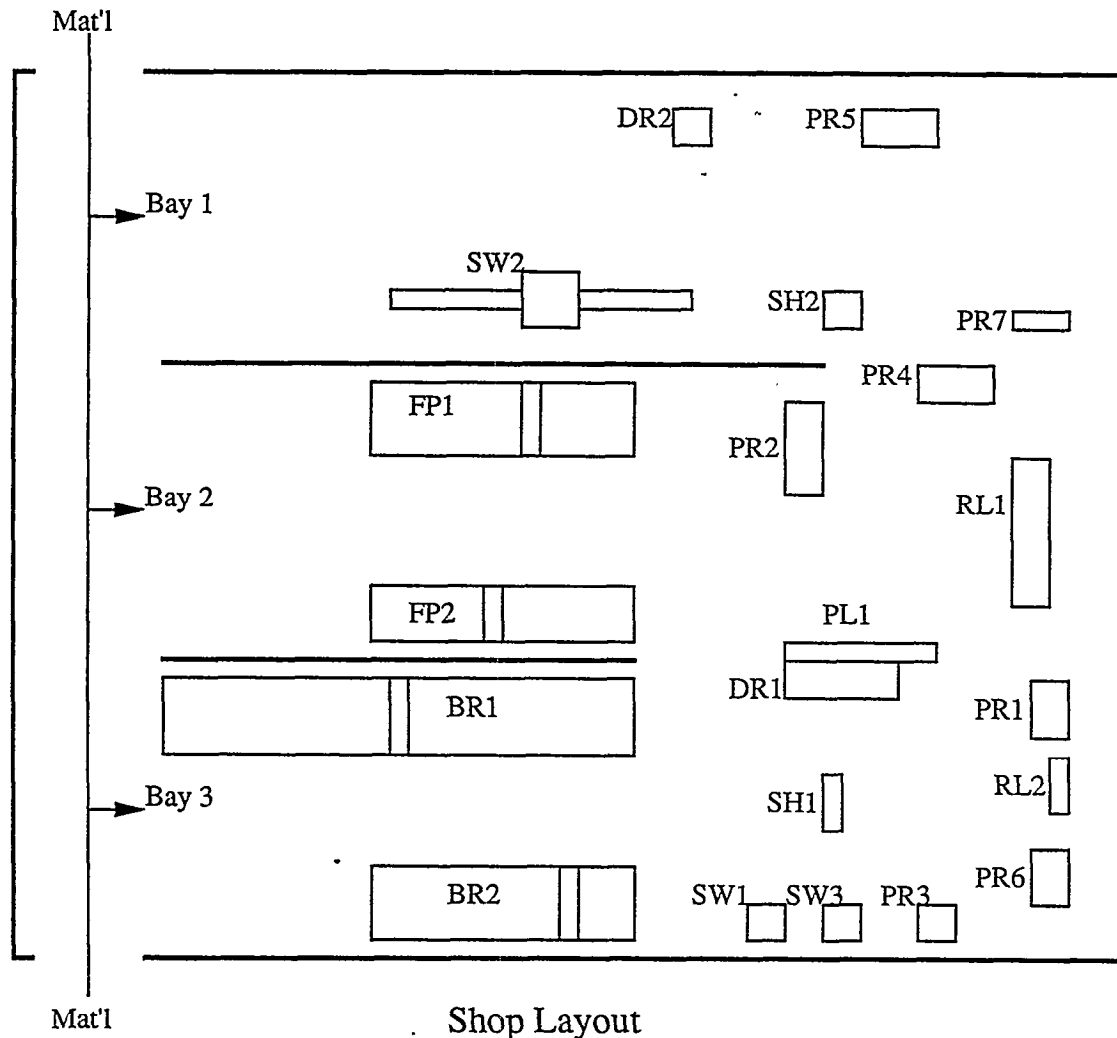


Figure 1

Form.

- . form accuracy
- . forming location
- . forming part depth maximum
- . forming part length maximum
- . forming part width maximum
- . forming routing code
- . outside radius minimum
- . roll degrees maximum
- . section modulus maximum

Definition of Rules

Following are the rules which have been established as representative of how the many production processes relate to the fabrication of specific parts. These rules are not intended to represent all of the production relationships within this facility. They represent only basic production relationships to help keep this example simple. Also, the detailed and accurate description of any domain is a continuous,

evolutionary process. As exceptions to the established rules are identified, existing rules are refined or additional rules are defined to address them. In its present state of development, this knowledgebase might, for example, narrow the cut process possibilities for the fabrication of a specific part to two specific processes from the eleven processes with cut capability. If this occurs, the rules established thus far do not provide enough knowledge to allow the system to decide between the remaining two processes; the rules require further refinement, or additional rules are required to address this particular exception.

Rule :

IF the part shape is rolled or knuckled,
THEN the part process is form process.

Rule :

IF the part edge/end preparation is beveled,
THEN the part process is edge prep process.

Rule 3:

IF the part size is smaller than stock,
THEN the part process is cut process.

Rule 4:

IF the part size is stock, and the part mat'l area is less than stock mat'l area (hole cut required),
THEN the part process is cut process.

Rule 5:

IF the part size is larger than stock,
THEN the part process is fabricate superpart (joining process).

Rule 6:

IF the part material is aluminum,
THEN the part thickness aluminum = part material thickness to be cut,
ELSE the part thickness aluminum = 0, and the part section modulus aluminum = 0.

Rule 7:

IF the part material is steel,
THEN the part thickness steel = part material thickness to be cut,
ELSE the part thickness steel = 0, and the part section modulus steel = 0.

Rule 8:

IF the part process is cut process,
and the part length \leq cut process cut part length max, and the part width \leq cut process cut part width max, and the part depth \leq cut process cut part depth max, and the part cut dimensional accuracy requirement \geq cut process cut accuracy, and the part thickness steel \leq cut process material cut thickness steel max, and the part thickness aluminum \leq cut process material cut thickness aluminum max, and the part hole cut diameter \leq cut process hole diameter max, and the part angle max variation from 90 degrees \leq cut process angle cut max, and the part cut configuration is the cut process cut configuration, and the part max cut length \leq cut process cut length max,
THEN the part cut method is Object Name <cut process>, and the part cut routing code is the cut process routing code, and the part cut location is the cut process cut location.

Rule 9:

IF the part process is form process,
and the part length \leq form process form part length max, and the part width \leq form process form part width max, and the part depth \leq form process form part depth max, and the part roll radius accuracy requirement \geq form process form accuracy, and the part section modulus steel \leq form process section modulus steel max, and the part section modulus aluminum \leq form process section modulus aluminum max, and the part outside radius \geq form process outside radius minimum, and the part roll degrees \leq form process roll degrees max, and the part web h/t \leq

the form process h/t max,

THEN the part forming method is Object Name <form process>, and the part forming routing code is the form process routing code, and the part forming location is the form process form location.

Rule 10:

IF the part process is edge prep process,
and the part length \leq edge prep process edge prep part length max, and the part width \leq edge prep process edge prep part width max, and the part depth \leq edge prep process edge prep part depth max, and the part max bevel angle required \leq edge prep process bevel degrees max, and the part thickness steel \leq edge prep process material edge prep thickness steel max, and the part thickness aluminum \leq edge prep process material edge prep thickness aluminum max, and the part edge prep configuration is the edge prep process edge prep configuration, and the part max edge prep length \leq edge prep process edge prep length max,
THEN the part edge prep method is Object Name <edge prep process>, and the part edge prep routing code is the edge prep process routing code, and the part edge prep location is the edge prep process edge prep location.

Rule 11:

IF the part type is plate,
THEN the part web h/t = 0, and the part material thickness to be cut = part depth.

Rule 12:

IF the part type is shape,
THEN the part web h/t = part depth * 0.94 / part web thickness, and part material thickness to be cut = part flange thickness.

As these rules were created, the "part" object and its associated attributes were created automatically by the expert system shell. No values were specified for the part attributes so that the expert system will prompt the user for these values during the inference process. Also, it is clear that some significant generalizations have been made within the rules for the purpose of simplification. These generalizations will probably require further refinement as the user encounters the specific circumstances where the rules do not provide sensible solutions.

A complete list of these rules in system format is provided in Appendix B.

Definition of Goals

The goals established for this expert system application are to identify the general processes, such as cut, edge prep, and/or form, required to produce a specified structural piece-part, and then to identify the specific shop processes in the defined facility that are required to carry out the general processes in producing the piece-part. In system language, the object attributes that have been identified for solution are:

- part process,
- part cut method,
- part cut routing code,
- part cut location,
- part forming method
- part forming routing code,
- part forming location,
- part edge prep method,
- part edge prep routing code, and
- part edge prep location.

USING THE EXPERT SYSTEM

Now that a knowledgebase has been created describing the structural piece-part production domain, the expert system can be used to identify production processes for various structural piece-parts based on part descriptions. The expert system will interactively prompt the user for information it does not have, like part characteristics, as the inference process proceeds.

Following are two examples of how the system identifies production processes for structural piece-parts. The inference processes carried out by the expert system for each part are described. Complete system listings of these two inference processes are also provided in Appendix C.

Part #1

Inference process. Part #1 in Figure 2 is a steel rolled T-bar with the toe of the web beveled at 60 degrees, and a part length of about 4.785 m (15.7 ft), which is less than the stock length of 6.096 m (20 ft). The system initially prompts the user for whether the part has shape, whether its edges are beveled, and whether the part is smaller than stock or, if not, whether its area in square feet is less than that of a stock piece. In this way the system can infer whether the part needs to be formed, edge prepped, or cut using Rules 1, 2, 3, 4, and 5. The system then prompts the user for all of the necessary part attribute information that is required to choose the specific shop processes necessary to produce the part using Rules 6-12 (there are too many of these to list individually here; refer to Appendix C for a detailed listing of the complete inference process). In this case, the user has specified that Part #1 requires a high level of accuracy in part length, roll radius, and bevel angle. The entire data entry and system inference process takes approximately 2.5 minutes.

Solution. The system properly concludes that Part #1 requires cutting, edge prep, and forming. The system then concludes that the edge prep method should be the edge planer, PL1, in Bay 2, the part cut method should be the hydraulic band saw, SW2, in Bay 1, and the forming process should be the frame bender, PR5, in Bay 1.

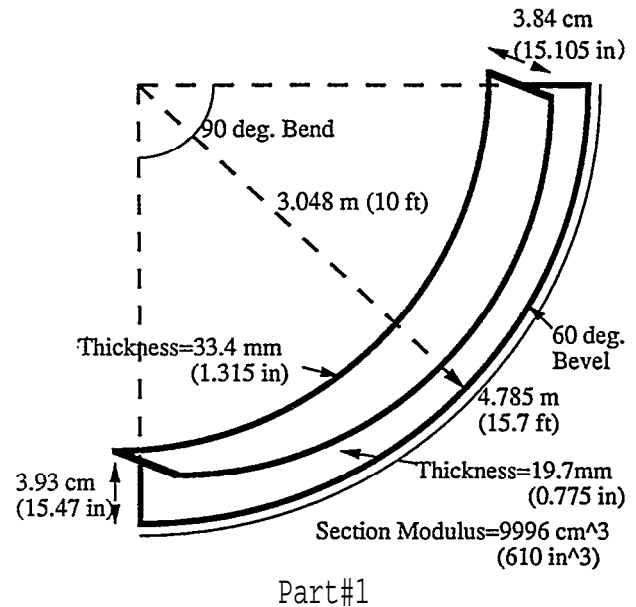


Figure 2

Comments. If the inference process provided in Appendix C is examined in detail, it can be seen that when Rule 9 was testing the 1500 ton press as a possible forming process for Part #1, the rule argument was determined to be "false" because of the tight part roll accuracy specified by the user. Had the user required less roll accuracy, the system might have concluded that the part could be formed on either the frame bender or the 1500 ton press, assuming all other part attributes, such as section modulus maximum, roll radius minimum, etc., met the remaining process limitations of the 1500 ton press.

Part #2

Inference process. Part #2 in Figure 3 is a 19 mm (3/4 in) flat steel plate which is stock length of 6.096 m (20 ft) on its long side, 4.877 m (16 ft) long on the opposite side, 2.438 m (8 ft) wide, symmetrical with two non-parallel straight edges, beveled at 45 degrees on all outer edges, with three cut-outs. Again, the system prompts the user for whether the part has shape, whether its edges are beveled, and whether the part is smaller than stock or, if not, whether its area in square feet is less than that of a stock piece to determine whether the part needs to be formed, edge prepped, or cut. The system then prompts the user for all of the necessary part attribute information that is required to choose the specific shop processes necessary to produce the part (again, refer to Appendix C for a detailed listing of the complete inference process). The entire data entry and system inference process again takes approximately 2.5 minutes.

Solution. The system properly concludes that Part #2 requires cutting, and edge prep. The system then concludes that the edge prep method could be either the edge planer, PL1, in Bay 2, or

the N/C plasma burning process, BR2, in Bay 3. The system also concludes that the part cut method could be either the N/C 2-axes burning process, BR1, or the N/C plasma burning process, BR2, both in Bay 3.

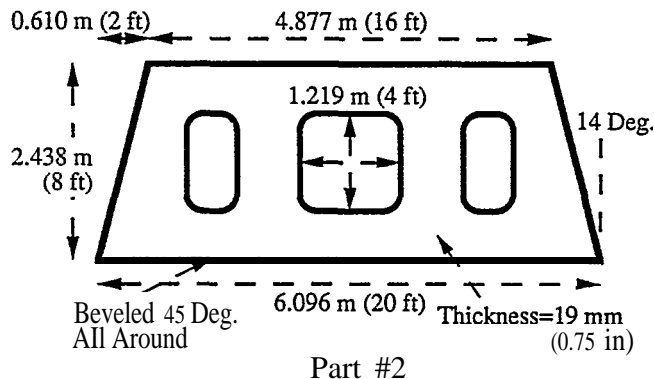


Figure 3

Comments. It is only sensible that if a part can be both cut and edge prepped using the same process, in this case the N/C plasma burning process, that process should be the only solution inferred for each of these fabrication needs. In this case, however, the rule necessary to make such a decision has not yet been created by the user. Therefore, the expert system must be refined to address this circumstance.

CONCLUSIONS

Expert System Development

Knowledge Acquisition. The process of knowledge acquisition is critical to the successful development of any expert system. Accurate and detailed domain information is an absolute necessity. The system can only be as smart as the developer; the old computer adage, "garbage in, garbage out" still applies.

When developing the rules which represent how a domain works, it is important to get beyond "rules of thumb" that are often quoted by the domain experts to the underlying logic of such rules. For instance, in the example presented in this paper, it would be easy to short-cut all of the comparisons of part attributes to process capabilities by simply creating rules that state that parts with certain characteristics are produced by certain specific processes. These type of rules ignore the underlying reasons for the decisions being made, and, if used, potential solution options might be missed simply because they had not been recognized previously by the domain experts.

Knowledge Engineering. It takes some practice for a user to learn the language, syntax, and format requirements of a particular expert system shell. However, shells have evolved to the point where anyone can build a functional, if not

elegant, expert system. In fact, some expert system shells today allow a user to create knowledgebases graphically using nodes with associated questions and lines of logical inference between nodes. Knowledge engineering for the example knowledgebase used in this paper took a relatively inexperienced user approximately four man-days.

Expert Systems Applications

Although the example expert system application presented in this paper is relatively basic, it still provides sensible and usable solutions for the processes required to produce certain structural piece-parts within the shop that has been defined. The next logical step with this particular application would be to refine the system to address exceptions which are identified in its use, and perhaps to expand the system to include manual processes, blast and paint processes, lay-off processes, and superpart fabrication processes.

Some might argue that the role of the expert system application presented in this paper is identical to the role of group technology in a similar manufacturing environment; that is to use part attributes to generate the production processes required to create that part. In an environment where product types and processes are fairly static over time, it may indeed make more sense to utilize group technology for this purpose because of the static, hard-coded nature of a group technology system. In an environment of rapidly changing and/or very different product types and processes, the flexibility that an expert system provides, allowing simple changes to attribute values and rules, may make the use of an expert system more suitable. The two systems might be complimentary in that an expert system could be used to help identify product families and work cells for a group technology system.

Beyond the identification of production processes, process durations and resource requirements could be identified based on part attributes, leading to potential cost estimating, scheduling, and resource management applications.

The cost estimating process would be ideal for expert systems application because of the level of uncertainty involved in the process, and because of the presence of cost estimating domain experts in most shipbuilding environments. The Australian Department of Defense is known to be exploring this potential application to help engineers develop ship configuration costs for comparison during design.

Constrained real-time scheduling, and resource management processes also seem potentially ideal for expert systems application because of the day-to-day uncertainties associated with these processes in a shipbuilding environment. This type of application is

currently being developed and has proven to be very complex because the scheduling and resource management domain is generally very large. If, however, all relevant domain data is available directly from a database in real time, an expert system can theoretically be developed to accomplish much of the scheduling and resource management process.

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APPENDIX A

System Listing of Objects and Attributes

OBJECTS	of	Mark's	HD:Papers:Paper.	Exprtsys.Plng:Real.Steel.Fab.7/12.kb/
100 ton punch				(general) (inherited from form process]
inherits from:				form accuracy (in. radius). (inherited from form process]
cut process				[Protection]
				Values:
(general (inherited from cut process]				= .2 (1.00)
# of axes (inherited from cut process]				forming location (inherited from form process]
[Protection]				[Protection]
values:				values:
= 1 (1.00)				is bay 3 (1.00)
# of master cut tools (inherited from cut process]				forming part depth max (in) (inherited from form process]
[Protection]				[Protection]
= 1 (1.00)				Values
# of slave cut tools (inherited from cut process]				=6(1.00)
[Protection]				forming part length max (ft) (inherited from form process]
values:				[Protection]
= 0 (1.00)				values:
angle cut max (deg) (inherited from cut process]				=25 (1.00)
[Protection]				forming part width max (ft) (inherited from form process]
values:				[Protection]
=0(1.00)				Values:
Automation Level (inherited from cut process]				-12 (1.00)
[Protection]				forming routing code [inherited from form process]
values:				[Protection]
= semi (1.00)				Values:
cut accuracy (in) (inherited from cut process]				is rt2(1.00)
values:				outsdo radius min (in) (inherited from form process]
=.01(1.00)				[Protection]
cut configuration (inherited from cut process]				Values:
[Protection]				-14 (1.00)
Values:				Roll Degrees Max [inherited from form process]
is single straight (1.00)				[Protection]
is parallel straight (1.00)				Values:
is non-parallel straight (1.00)				- 360 (1.00)
is hole (1.00)				section modulus max., alum (in ³) (inherited from form process]
cut length max (h)(inherited from cut process]				[Protection]
Values:				..
= .75 (1.00)				= 157 (1.00)
cut location (inherited from cut process]				section modulus max. steel (in ³) (inherited from form process]
[Protection]				[Protection]
Values:				.
is bay 1 (1.00)				= 54 (1.00)
cut part depth max (in) (inherited from cut process]				web h/t max (inherited from form process]
[Protection]				[Protection]
Values:				.
=4 (1.00)				=0(1.00)
cut part length max (ft) (inherited from cut process]				1500 Ton Press
[Protection]				inherits from:
values:				form process
= 40 (1.00)				(general) (inherited from form process]
cut part width max (ft) (inherited from cut process]				form accuracy (in. radius) (inherited from form process]
[Protection]				[Protection]
Values:				.
= .75 (1.00)				- .1 (1.00)
cut routing cod.3 (inherited from cut process]				forming location [inherited from form process]
values:				[protection]
=sh2(1.00)				values:
hole diameter max (in) (inherited from cut process]				is bay 2 (1.00)
[Protection]				toning part depth max (in) (inherited from form process]
Values:				[Protection]
=3(1.00)				values:
marl cut thickness max. alum (in) (inherited from cut process]				= 22 (1.00)
[Protection]				forming part length max (ft) Inherited from form process]
Values:				[Protection]
=1 (1.00)				Values:
marl cut thickness max. steel (in) (inherited from cut process]				= 35 (1.00)
[Protection]				forming part width max (ft) (inherited from form process]
Values:				
=.375 (1.00)				values:
12 Foot Roll				=1 20 (1.00)
inherits from:				forming muting code (inherited from form process]
form process				[Protection]
				Values:
				is pr2 (1.00)

outside radius min (in) [Protection] Values: = 22 (1.00)	(inherited from form process)	forming part depth max (in) [Protection] Values: = 12 (1.00)	(inherited from form process)
Roll Degress Max [Protection] =180 (1.00)	(inherited from form process)	forming part length max (ft) [Protection] Values: = 20 (1.00)	(inherited from form Process)
section modulus max. alum [Protection] values: = 1044 (1.00)	(in ³) (inherited from form process)	forming part width max (Ft) [Protection] Values: =4(1.00)	(inherited from form process)
section modulus max. steel [Protection] Values: =360 (1.00)	(in ³) (inherited from form process)	forming muting code [Protection] Values: is pr6 (1.00)	(inherited from form process)
web h/t max [Protection] Values: = 20 (1.00)	(Inherited from form process)	outside radius min (in) [Protection] Values: = 17 (1.00)	(inherited from form process)
2000 Ton Roll inherits from: form process		Roll Degrees Max [Protection] Values: = 180 (1.00)	(inherited from form process)
(general) (inherited from form process)		section modulus max. alum [Protection] Values: = 52 (1.00)	(in ³) (inherited from form process)
form accuracy (in. radius) [Protection] values: = .1 (1.00)	(inherited from form process)	section modulus max. steel [Protection] values: = 18 (1.00)	(in ³) (inherited from form process)
farming location [Protection] Values: is bay 2 (1.00)	(inherited from form process)	web h/t max [Protection] Values: = 22 (1.00)	(inherited from form process)
forming part depth max (in) [Protection] Values: =11 (1.00)	(inherited from form process)	37.5 Ton Press inherits from: form process	
forming part length max (ft) [Protection] Values: = 40 (1.00)	(inherited from form process)	(general) (inherited from form process)	
forming part width max (ft) [Protection] Values: = 45 (1.00)	(inherited from form process)	form accuracy (in. radius) [Protection] Values: = .1 (1.00)	(inherited from form process)
forming muting code [Protection] Values: is rll (1.00)	(inherited from form process)	forming location [Protection] is bay 3 (1.00)	(inherited from form process)
outside radius min (in) [Protection] Values: = 24 (1.00)	(inherited from form process)	forming part depth max (in) [Protection] values: =4 (1.00)	(inherited from form process)
Roll Degrees Max [Protection] Values: = 180 (1.00)	(inherited from form process)	forming part length max (ft) [Protection] values: = 8 (100)	(inherited from form process)
section modulus max. alum [Protection] Values: =4176 (1.00)	(in ³) (inherited form form process)	forming part width max (ft) [Protection] values: =1 (1.00)	(inherited from form process)
section modulus max. steel [Protection] = 1440 (1.00)	(in ³) (inherited from form process)	forming muting code [Protection] values: is pn (1.00)	(inherited from form process)
web h/t mu [Protection] Values: = 0(1.00)	(inherited from form process)	outside radius min (in) [Protection] Values: =4 (1.00)	(inherited from form process)
250 Ton Press inherits from: form process		Roll Degrees Max [Protection] =360 (1.00)	(inherited from form process)
(general) (inherited from form process)		Section modulus max. alum [Protection] = 23 (1.00)	(in ³) (inherited from form process)
form accuracy (in. radius) [Protection] values: = .2 (1.00)	(inherited from form process)	section modulus max. steel [Protection] = 8 (1.00)	(in ³) (inherited from form process)
forming location (inherited from form process) Values: is bay 3 (1.00)			

web h/t max (inherited from form process)
[Protection]
 = 20 (1.00)

60 Ton Cold Press
 inherited from:
 form process

(general) (inherited from form process)

form accuracy (in. radius) (inherited from form process)
[Protection]
 values:
 = .15 (1.00)

forming location (inherited from form process)
[Protection]
 Values:
 is bay 1 (1.00)

forming part depth max (in) (inherited from form process)
[Protection]
 Values:
 = 17 (1.00)

forming part length max. (ft) (inherited from form process)
[Protection]
 Values:
 = 20 (1.00)

forming part width max (ft) (inherited from form process)
[Protection]
 Values:
 = 5 (1.00)

forming muting code (inherited from form process)
[Protection]
 Values:
 is pr7 (1.00)

outside radius min (in) (inherited from form process)
[Protection]
 Values:
 = 0 (1.00)

Roll Degrees Max (inherited from form process)
[Protection]
 Values:
 = 0 (1.00)

section modulus max. alum (in³) (inherited from form process)
[Protection]
 Values:
 = 35 (1.00)

section modulus max. steel (in³) (inherited from form process)
[Protection]
 values:
 = 12 (1.00)

web h/t max (inherited from form process)
[Protection]
 values:
 = 24 (1.00)

600 Ton Press
 inherits from:
form process

(general) (inherited from form process)

form accuracy (in. radius) (inherited from form process)
[Protection]
 Values:
 = .1 (1.00)

forming location (inherited from form process)
[Protection]
 Values:
 is bay 2 (1.00)

forming part depth max (in) (inherited from form process)
[Protection]
 Values:
 = 15 (1.00)

forming part length max (ft) (inherited from form process)
[Protection]
 Values:
 = 17 (1.00)

forming part width max (ft) (inherited from form process)
[Protection]
 Values:
 = 12 (1.00)

forming routing code (inherited from form process)
[Protection]
 Values:
 is pr4 (1.00)

outside radius min (in) (inherited from form process)
[Protection]
 = 15 (1.00)

Roll Degrees Max (inherited from form process)
[Protection]
 Values:
 = 180 (1.00)

section modulus max. alum (in³) (inherited from form process)
[Protection]
 values:
 = 278 (1.00)

section modulus max. steel (in³) (inherited from form process)
[Protection]
values:
= 96 (1.00)

web h/t max (inherited from form process)
[Protection]
 values:
 = 20 (1.00)

bandsaw
 inherits from:
 cut process

(general) [inherited from cut process]

of axes [inherited from cut process]
[Protection]
= 1 (1.00)

of master cut tools (inherited from cut process)
[Protection]
 Values:
 = 1 (1.00)

of slave cut tools [inherited from cut process]
[Protection]
 = 0 (1.00)

angle cut max (deg) (inherited from cut process)
[Protection]
 values:
 = 45 (1.00)

Automation Level [inherited from cut process]
[Protection]
 values:
 = semi (1.00)

cut accuracy (in) [inherited from cut process]
[Protection]
 Values:
 = .05 (1.00)

cut configuration [inherited from cut process]
[Protection]
 values:
 is non-parallel straight (1.00)
 is parallel straight (1.00)
 is single straight (1.00)

cut length max (h) (inherited from cut process)
[Protection]
 Values:
 = -3 (1.00)

cut location (inherited from cut process)
[Protection]
 values:
 is bay 3 (1.00)

cut part depth max (in) [inherited from cut process]
[Protection]
 Values:
 = -4 (1.00)

cut part length max (h) (inherited from cut process)
[Protection]
 Values:
 = -4 (1.00)

cut part width max (h) [inherited from cut process]
[Protection]
 Values:
 = -3 (1.00)

cut routing code [inherited from cut process]
[Protection]
 Values:
 is SW1 (1.00)

hole diameter max (in) (inherited from cut process)
 [Protection]
 values:
 -0 (1.00)

man cut thickness max, alum (in) (inherited from cut process)
 [Protection]
 values:
 = 3 (1.00)

marl cut thickness max, steel (in) [inherited from cut process]
 [Protection]
 Values:
 =1 (1.00)

Brake Press
 inherits from:
 form process
 (general) (inherited from form process)
 form accuracy (in. radius) [inherited from form process]
 [Protection]
 values:
 - .15 (1.00)

f o r m i n g location (inherited from form process)
 Protection
 values:
 is bay 3 (1.00)

forming part depth max (in) (inherited from form process)
 [Protection]
 values:
 -15 (1.00)

forming part length max (h) [inherited from form process]
 [Protection]
 values:
 -35 (1.00)

forming part width max (h) [inherited from form process]
 [Protection]
 values:
 -12 (1.00)

forming routing cods [inherited from form process]
 [Protection]
 values:
 is pr1 (1.00)

outside radius min (In) [inherited from form process]
 [Protection]
 values:
 - 12 (1.00)

Roll Degrees Max [inherited from form process]
 [Protection]
 values:
 - 180 (1.00)

section modulus max. alum (in 3) [inherited from form process]
 (Protection)
 values:
 - 213 (1.00)

Section modulus max. steel (in 3) [inherited from form process]
 [Protection]
 Values:
 -74 (1.00)

web h/t max [inherited from form process]
 [Protection]
 values:
 -20 (1.00)

contour band saw
 inherits from:
 cut process
 (general) (inherited from cut process)
 # of axes [inherited from cut process]
 [Protection]
 values:
 -2 (1.00)

of master cut tools (inherited from cut process)
 [Protection]
 Values:
 -1 (1.00)

of slave cut tools [inherited from cut process]
 [Protection]
 values:
 - 0 (1.00)

angle cut max (deg) [inherited from cut process]
 [Protection]
 values:
 - 45 (1.00)

Automation Level [inherited from cut process]
 [Protection]
 values:
 - semi (1.00)

cut accuracy (in) [inherited from cut process]
 [protection]
 values:
 = .02 (1.00)

cut configuration [inherited from cut process]
 [Protection]
 Values:
 is contour (1.00)
 is non-parallel staight (1.00)
 is parallel straight (1.00)
 is single straight (1.00)

cut length max (h) [inherited from cut process]
 [Protection]
 values:
 =2(1.00)

cut location [Inherited from cut process]
 [Protection]
 values:
 is bay 3 (1.00)

cut part depth max (in) [inherited from cut process]
 [protection]
 values:
 = 12 (1.00)

cut part length max (ft) [inherited from cut process]
 [Protection]
 Values:
 =8(1.00)

cut part width max (ft) [inherited from cut process]
 [Protection]
 values:
 =2(1.00)

cut routing code [inherited from cut process]
 [Protection]
 values:
 is sw3 (1 .00)

hole diameter max (in) [inherited from cut process]
 [Protection]
 values:
 =0 (1.00)

marl cut thickness max. alum (in) [inherited from cut process]
 [Protection]
 values:
 = 6 (1.00)

marl cut thickness max. steel (in) [inherited from cut process]
 [Protection]
 values:
 = 2 (1.00)

cut process
 is inherited by:
 drill #2
 100 ton punch
 band saw
 contour tend saw
 drill #1
 Flame Plane 1
 Flame Plane 2
 hydraulic tend saw
 N/C 2-Axis
 N/C Plasma
 shear

(general)
 #Of axes
 # of master cut tools
 # of slave cut tools
 angle cut max (deg)
 Automation Level
 cut accuracy (in)
 cut configuration
 cut length max (ft)

cut location

cut part **depth** max (in)

cut part length max (ft)

cut part width max (ft)

cut routing code

hole diameter max (in)

marl cut thickness max. alum (in)

marl cut thickness max. steel (in)

drill #1

inherits from:
cut process

(general) [inherited from cut process]

f a x e s [inherited from cut process]
[Protection]
values:
=1 (1.00)

of master cut tools [inherited from cut process]
[Protection]
values:
-1 (1.00)

of slave cut tools (inherited from cut process)
[Protection]
values:
= 0 (1.00)

angle cut max (deg) (inherited from cut process)
[Protection]
Values:
=0 (1.00)

Automation Level [inherited from cut process]
[Protection]
values:
= semi (1.00)

cut accuracy (in) (inherited from cut process)
[Protection]
values:
= .005 (1.00)

art configuration (inherited from cut process)
[Protection]
Values:
is hole (1.00)

art length max (in) [inherited from cut process]
[Protection]
Values:
=25 (1.00)

cut location (inherited from cut process)
[Protection]
values:
is bay 1 (1.00)

cut part depth max (in) [inherited from cut process]
[Protection]
Values:
= 15 (1.00)

cut part length max (ft) [inherited from cut process]
[Protection]
Values:
= 25 (1.00)

cut part width max (ft) [inherited from cut process]
[Protection]
values:
=3(1.00)

cut muting code [inherited from cut process]
[Protection]
values:
is dr1 (1.00)

hole diameter max (in) [inherited from cut process]
[Protection]
values:
= 3 (1.00)

marl cut thickness max. alum (in) (inherited from cut process)
[Protection]
values:
=6(1.00)

marl cut thickness max. steel (in) [inherited from cut process]
[Protection]
values:
=6(1.00)

drill #2

inherits from:
cut process

(general) (inherited from cut process)

of axes [inherited from cut process]
[Protection]
values:
= 1 (1.00)

of master cut tools [inherited from cut process]
[Protection]
Values:
= 1 (1.00)

of slave cut mob [inherited from cut process]
[Protection]
values:
= 0 (1.00)

angle cut max (dog) [inherited from cut process]
[Protection]
values:
=0(1.00)

Automation Level [inherited from cut process]
[Protection]
Values:
=semi (1.00)

cut accuracy (in) (inherited from cut process)
[protection]
values:
= .005 (1.00)

an configuration (inherited from cut process)
[Protection]
values:
is hole (1.00)

cut length max (ft) [inherited from cut process]
Protection
Values:
= 35 (1.00)

cut location [inherited from cut process]
[Protection]
values:
is bay 3 (1.00)

cut part depth max (in) (inherited from cut process)
[Protection]
values:
= 10 (1.00)

cut part length max (ft) [inherited from cut process]
[Protection]
values:
= 35 (1.00)

cut part width max (ft) [inherited from cut process]
[Protection]
values:
=12 (1.00)

cut routing code [inherited from cut process]
[Protection]
Values:
is dr2 (1.00)

hole diameter max (in) [inherited from cut process]
[Protection]
values:
=4 (1.00)

marl cut thickness max. alum (in) (inherited from cut process)
[Protection]
values:
=6(1.00)

man cut thickness max. steel (in) [inherited from cut process]
[Protection]
values:
= 6 (1.00)

edge planer

inherits from:
edge **prep** process

(general) (inherited from edge prep process)

bevel accuracy (deg) (inherited from edge prep process)
 [Protection]
 values:
 = 2 (1.00)

bevel Configuration (inherited from edge prep Process)
 [Protection]
 values:
 is single straight (1.00)
 is parallel straight (1.00)
 is non-parallel straight (1.00)

Bevel Degrees Max (inherited from edge prep process)
 [Protection]
 values:
 =80 (1.00)

edge prep length max (ft) (inherited from edge prep process)
 [Protection]
 values:
 =36 (1.00)

edge prep location (inherited from edge prep process)
 [Protection]
 values:
 is bay 2 (1.00)

edge prep PM depth max (in) (inherited from edge prep process)
 [Protection]
 Values:
 = 18 (1.00)

edge prep part length max (ft) (inherited from edge prep process)
 [Protection]
 Values:
 =36 (1.00)

edge prep pan width max (ft) (inherited from edge prep process)
 [Protection]
 values:
 = 20 (1.00)

edge prep routing code (inherited from edge prep process)
 [Protection]
 values:
 is pl1 (1.00)

edge prep thickness max. alum (in) (inherited from edge prep process)
 [Protection]
 values:
 =4 (1.00)

edge prep thickness max. steel (in) (inherited from edge prep process)
 [Protection]
 Values:
 =4(1.00)

edge prep process
 is inherited by:
 Flame Plane 1
 H/C Plasma
 edge planer

(general)

bevel accuracy (dog)

bevel configuration

Bevel Degrees Max

edge prep length max (ft)

edge prep location

edge pep part depth max (in)

edge prep pan length max (ft)

edge prep part width max (ft)

edge prep routing code

edge prep thickness max. alum (in)

edge prep thickness max. steel (in)

Flame Plane:

inherits from:

cut process

edge prep process

(general) {inherited from edge prep process}

(general) {inherited from cut process}

of axes {inherited from cut process}

[Protection]
 values:
 = 1 (1.00)

of master cut mob (inherited from cut process)
 [Protection]
 values:
 = 11 (1.00)

of slave cut tools (inherited from cut process)
 [Protection]
 values:
 =0(1.00)

angle cut max (deg) (inherited from at process)
 [Protection]
 values:
 =0(1.00)

Automation Level (inherited from cut process)
 [Protection]
 Values:
 is semi (1.00)

bevel accuracy (deg) (inherited from edge prep process)
 [Protection]
 values:
 =2(1.00)

bevel configuration (inherited from edge prep process)
 [Protection]
 values:
 is single straight (1.00)
 is parallel straight (1.00)

Bevel Degrees Max (inherited from edge prep process)
 [Protection]
 values:
 = 60 (1.00)

cut accuracy (in) (inherited from cut process)
 [Protection]
 Values:
 = .05 (1.00)

cut configuration (inherited from at process)
 [Protection]
 values:
 is parallel straight (1.00)
 is single straight (1.00)

cut length max (ft) (inherited hum cut process)
 [Protection]
 Values:
 =50 (1.00)

at location (inherited from cut process)
 [Protection]
 Values:
 is bay 2 (1.00)

cut part depth max (in) (inherited from cut pocess)
 [Protection]
 values:
 = 10 (1.00)

cut part length max (ft) (inherited from cut process)
 [Protection]
 Values:
 = 50 (1.00)

cut part width max (ft) (inherited from cut process)
 [Protection]
 Values:
 = 16 (1.00)

cut routing code (inherited from cut process)
 [Protection]
 is \$1 (1.00)

edge prep length max (ft) (inherited from edge prop process)
 [protection]
 Values:
 = 50 (1.00)

edge prep location (inherited from edge prep process)
 [Protection]
 is bay 2 (1.00)

edge prep part depth max (in) (inherited hum edge prop process)
 [Protection]
 Values:
 - 10 (1.00)

edge prep part length max (ft) (inherited from edge prep process)
 protection]
 Values:
 -50 (1.00)

edge prep part width max (ft) (inherited from edge prep process)
 [Protection]
 Values:
 16 (1.00)

edge prep routing code (inherited from edge prep process)
 [Protection]
 values:
 is fp1 (1.00)

edge pep thickness max. alum (in) (inherited from edge prep process)
 [Protection]
 values:
 = 0 (1.00)

edge prep thickness max. steel (in) (inherited from edge prep process)
 [Protection]
 values:
 = 6 (1.00)

hole diameter max. (in) (inherited from cut process)
 [Protection]
 values:
 - 0 (1.00)

mail cut thickness max. alum (in) (inherited from cut process)
 [Protection]
 Values:
 - 0 (1.00)

man cat thickness max. steel (in) (inherited from cut process)
 [Protection]
 values:
 - 6 (1.00)

Flame Plane 2

inherits from:
 cut process

(general) (inherited from cut process)

of axes (inherited from cut process)
 [Protection]
 values:
 = 1 (1.00)

of master cut tool5 (inherited from cut process)
 [Protection]
 values:
 - 2 (1.00)

x of stave cut tool3 (inherited from cut process)
 [Protection]
 Values:
 - 0 (1.00)

angle cut max (deg) (inherited from cut process)
 [Protection]
 Values:
 . 0 (1.00)

Automation Level (inherited from cut process)
 [Protection]
 Values:
 is semi (1.00)

cut accuracy (in) (inherited from cut process)
 [Protection]
 Values:
 - .03 (1.00)

cut configuration (Inherited from cut process)
 [Protection]
 Values:
 is parallel straight (1.00)
 is single staight (1.00)

cut length max (ft) (inherited from cut process)
 [Protection]
 values:
 - 50 (1.00)

cut location (inherited from cut process)
 [Protection]
 values:
 is bay 2 (1.00)

cu' part depth max (in) (inherited from cut process)
 [Protection]
 Values:
 - 4 (1.00)

cut part length max (ft) (inherited from cut process)
 [Protection]
 Values:
 PM (1.00)

cut part width max (ft) (inherited from cut process)
 [Protection]
 Values:
 = 12 (1.00)

cut routing code (inherited from cut process)
 [Protection]
 values:
 is fp2 (1.00)

hole diameter max (in) (inherited from cut process)
 [Protection]
 values:
 = 0 (1.00)

man cut thickness max. alum (in) (inherited from cut process)
 [Protection]
 values:
 - 0 (1.00)

man cut thickness max. steel (in) (inherited from cut process)
 [Protection]
 values:
 - 4 (1.00)

form process
 is inherited by:
 12 Foot Roll
 250 Ton Press
 37.5 Ton Press
 60 Ton Cold Press
 600 Ton Press
 Brake Press
 1500 Ton Press
 X100 Ton Roll
 Frame Bender

(general)

from accuracy (in. radius)

forming location

forming part depth max (in)

forming part length max (ft)

forming part width max (ft)

forming routing code

outside radius min (in)

Roll Degrees Max

section modulus max. alum (in^3)

section modulus max. steel (in^3)

web h/ max

Frame Bender
 inherits from:
 form process

(general) (inherited from form process)

form accuracy (in. radius) (inherited from form process)
 [Protection]
 values:
 - .05 (1.00)

forming location (Inherited from form process)
 [Protection]
 values:
 is bay 1 (1.00)

forming part depth max (in) (inherited from form process)
 [Protection]
 values:
 - 30 (1.00)

forming part length max (ft) (inherited from form process)
 [Protection]
 values:
 - 40 (1.00)

forming part width max (ft) (inherited from form process)
 [Protection]
 Values:
 - 1.5 (1.00)

forming muting code (inherited from form process)
 [Protection]
 values:
 is pr5 (1.00)

outside radius min (in) (inherited from form process)
 [Protection]
 values:
 = 60 (1.00)

Roll Degrees Max (inherited from form process)
 [Protection]
 values:
 = 270 (1.00)

section modulus max. alum (in³) (inherited from form process)
 values:
 = 3000 (1.00)

section modulus max. steel (in³) (inherited from form process)
 values:
 = 1000 (1.00)

web h / t (inherited from form process)
 values:
 124 (1.00)

hydraulic band saw
 inherits from:
 cut process

(general) (inherited from cut process)

of axes (inherited from cut process)
 values:
 -1 (1.00)

of master cut tools (inherited from cut process)
 values:
 - 1 (1.00)

of slave cut tools (inherited from cut process)
 values:
 - 0 (1.00)

angle cut max (deg) (inherited from cut process)
 values:
 - 45 (1.00)

Automation Level (inherited from cut process)
 values:
 is semi (1.00)

cut accuracy (ii) (inherited from cut process)
 values:
 - .02 (1.00)

cut configuration (inherited from cut process)
 values:
 is parallel straight (1.00)
 is single straight (1.00)
 is non-parallel straight (1.00)

cut length max (ft) (inherited from cut process)
 values:
 - 1.5 (1.00)

cut location (inherited from cut process)
 values:
 is bay 1 (1.00)

cut part depth mu (in) (inherited from cut process)
 values:
 - 20 (1.00)

cut part length max (ft) (inherited from cut process)
 values:
 - 40 (1.00)

cut part width max (ft) (inherited from cut process)
 values:
 - 1.5 (1.00)

cut routing code (inherited from cut process)
 values:
 is SW2 (1.00)

hole diameter max (in) (inherited from cut process)
 values:
 - 0 (1.00)

man cut thickness max, alum (in) (inherited from cut process)
 values:
 - 6 (1.00)

matl cut thickness max. steel (in) (inherited from cut process)
 values:
 - 3 (1.00)

NIC 2-Axis
 inherits from:
 cut process

(general) (inherited from cut process)

of axes (inherited from cut process)
 values:
 - 2 (1.00)

of master cut tools (inherited from cut process)
 values:
 - 2 (1.00)

of slave cut tools (inherited from cut process)
 values:
 - 2 (1.00)

angle cut max (deg) (inherited from cut process)
 values:
 - 360 (1.00)

Automation Level (inherited from cut process)
 values:
 - N/C (1.00)

cut accuracy (in) (inherited from cut process)
 values:
 - .02 (1.00)

cut configuration (inherited from cut process)
 values:
 is parallel straight (1.00)
 is non-parallel straight (1.00)
 is single straight (1.00)
 is contour (1.00)
 is hole (1.00)

cut length max (ft) (inherited from cut process)
 values:
 - 140 (1.00)

cut location (inherited from cut process)
 values:
 is bay 3 (1.00)

cut part depth max (in) (inherited from cut process)
 values:
 - 6 (1.00)

cut part length max (ft) (inherited from cut process)
 values:
 - 140 (1.00)

cut part width max (ft) (inherited from cut process)
 values:
 - 16 (1.00)

cut routing code (inherited from cut process)
 values:
 is br1 (1.00)

hole diameter max (in) (inherited from cut process)
 values:
 - 138 (1.00)

matl cut thickness max. alum (in) (inherited from cut process)
 values:
 - 0 (1.00)

matl cut thickness max, steel (in) (inherited from cut process)
 values:
 - 6 (1.00)

N/C Plasma
 inherits from:
 cut process
 edge prep process

(general) (inherited from edge prep process)

(general) (inherited from cut process]

of axes (inherited from cut process)
[Protection]
values:
= 3 (1.00)

of master cut tools (inherited from cut process)
[Protection]
values:
= 2 (100)

of slave cut tools (inherited from cut process]
[Protection]
values:
= 2 (1.00)

angle cut max (deg) (inherited from cut process)

values: [Protection]
= 360 (1.00)

Automation Level (inherited from cut process)
[Protection]
values:
is N/C (1.00)

bevel accuracy (deg) [inherited from edge prep process]
[Protection]
values:
= .5 (1.00)

bevel configuration (inherited from edge prep process]
[Protection]
values:
is single straight (1.00)
is parallel straight (1.00)
is non-parallel straight (1.00)
is contour (1.00)

Bevel Degrees Max (inherited from edge prep process)
[Protection]
values:
= 70 (1.00)

cut accuracy (in) (inherited from cut process)
values: [Protection]
= .02 (1.00)

cut configuration (inherited from cut process]
[Protection]
values:
is parallel straight (1.00)
is single straight (1.00)
is non-parallel straight (1.00)
is contour (1.00)
is hole (1.00)

cut length max (ft) (inherited from cut process]
[Protection]
values:
= 50 (1.00)

cut location (inherited from cut process]
[Protection]
values:
is bay 3 (1.00)

cut part depth max (in) (inherited from cut process)
values: [Protection]
= 6 (1.00)

cut part length max (ft) (inherited from cut process)
[Protection]
values:
= 50 (1.00)

cut part width max (ft) (inherited from cut process)
[Protection]
values:
= 18 (1.00)

cut routing code (inherited from cut process)
[Protection]
values
is br2 (1.00)

edge prep length max (ft) (inherited from edge prep process)
[Protection]
values:
= 50 (1.00)

edge prep location (inherited from edge prep process)
[Protection]
values:
is bay 3 (1.00)

edge prep part depth max (in) (inherited from edge prep process)
[Protection]
values:
= 6 (1 .00)

edge prep part length max (ft) (inherited from edge prep process]
[Protection]
values:
= 50 (1.00)

edge prep part width max (ft) (inherited from edge prep process]
values: [Protection]
= 18 (1.00)

edge pep routing code (inherited from edge prep process)
[Protection]
values:
is br2 (1.00)

edge prep thickness max. alum (in) (inherited from edge prep process)
values: [Protection]
= 3 (1.00)

edge prep thickness max. stool (in) (inherited from edge prep process)
[Protection]
values:
= .75 (1.00)

hole diameter max (in) (inherited from cut process)

values: [Protection]
= 216 (1.00)

man cut thickness max. alum (in) (inherited from cut process)
[Protection]
values:
= 3 (1.00)

man cut thickness max. steel (in) (inherited from cut process)
[Protection]
values:
= .75 (1.00)

part

angle max var. from 90 dog
[No Auto Values]

area. sq.ft.
automatic values:
is less than stock area, sq.ft.

bevel configuration
automatic values:
is single straight
is parallel straight
is non-parallel straight
is contour

cut configuration
automatic values:
is hole
is single straight
is parallel straight
is non-parallel straight
is contour
is non-parallel straight
is parallel straight
is single straight

cut dimensions accuracy requirement (in)
automatic values:
= .005
= .01
= .05
= .02
= .03

cut location
[No Auto values]

cut method
[No Auto Values]

cut muting code
[No Auto Values]

depth (in)
[No Auto Values]

edge prep location
[No Auto Values]

edge prep method
[No Auto Values]

edge prep routing code
[No Auto Values]

edge/end preparation	# of master cut tools	(Inherited from cut process)
automatic values:	[Protection]	
is beveled	values:	
	=	(1.00)
flange thickness (in)	# of slave cut tools	(inherited from cut process)
	values: [Protection]	
forming location	=	0 (1.00)
[No Auto Values]		
forming method	angle cut max (deg)	(inherited from cut process)
(No Auto Values)	[Protection]	
forming routing code	values:	
[No Auto Values]	=	0 (1.00)
hole cut diameter (in)	Automation Level	(inherited from cut process)
[No Auto Values]	values: [Protection]	
length (ft)	=	semi (1.00)
[No Auto Values]		
man thickness to be cut (in)	cut accuracy (in)	[inherited from cut process]
[No Auto Values]	[Protection]	
material	values:	
automatic values:	=	.03 (1.00)
is alum		
is steel	cut configuration	(inherited from cut process)
	[Protection]	
max bevel angle required	values:	
[No Auto Values]	is single straight (1.00)	
max cut length (ft)	is parallel straight (1.00)	
[No Auto Values]	is nonparallel straight (1.00)	
max edge prep length (ft)	cut length max (ft)	(inherited from cut process)
(No Auto Values)	[Protection]	
outside radius (in)	values:	
[No Auto Values]	=	10 (1.00)
process	cul location	(inherited from cut process)
[No Auto Values]	[Protection]	
roll degrees	values:	
[No Auto Values]	is bay 3 (1.00)	
roll radius accuracy requirement (in)	cut part depth max (in)	(inherited from cut process)
automatic values:	[Protection]	
= .2	values:	
= .1	=	6 (1.00)
= .15	cut part length max (ft)	[inherited from cut process]
= .05	[Protection]	
section modulus alum	values:	
[No Auto Values]	=	18 (1.00)
section modulus steel	cut part width max (ft)	[inherited from cut process]
[No Auto Values]	values: [Protection]	
shape	=	10 (1.00)
automatic values:	cut routing code	(inherited from cut process)
is rolled	[Protection]	
is knuckled	values:	
	is sh1 (1.00)	
size	hole diameter max (in)	(inherited from cut process)
automatic values:	values: [Protection]	
is smaller than stock	=	0 (1.00)
is stock		
is larger than stock	man cut thickness max, alum (in)	(inherited from cut process)
thickness alum	[Protection]	
[No Auto Values]	values:	
thickness steel	=	1.5 (1.00)
[No Auto Values]	man cut thickness max, steel (in)	(inherited from cut process)
type	[Protection]	
automatic values:	values:	
is plate	=	.5 (1.00)
is shape		
web h/t	... OBJECTS ...	
[No Auto Values]		
web thickness (in)		
width (ft)		
[No Auto Values]		
shear		
inherits from:		
cut process		
(general)	[inherited from cut process]	
# of axes	(inherited from cut process)	
[Protection]		
values:		
= 1 (1.00)		

APPENDIX B

System Listing of Rules

. * * R U L E S . . . of Marks HD:Papers:Paper, Exprt.Sys.Plng:Real.Steel.Fab.7/12.kb . . .

RULE #1 priority 50 -

```
IF -----
(1) the part shape is rolled [threshold 0.20]
(2) or the part shape is knuckled [threshold 0.201]
THEN -----
(1) part process is "form process" [certainty 1.001]
```

RULE #2 priority 50 -

```
IF -----
(1) the part edge/end preparation is beveled [threshold 0.201]
THEN -----
(1) part process is "edge prep process" [certainty 1.00]
```

RULE #3 priority 50 -

```
IF -----
(1) the part size is "smaller than stock" [threshold 0.20]
THEN -----
(1) part process is "cut process" [certainty 1.00]
```

RULE #4 priority 50 -

```
IF -----
(1) the part size is stock [threshold 0.20]
(2) and the part area, sq.ft. is "less than stock area, sq.ft." [threshold 0.201]
THEN -----
(1) part process is "cut process" [certainty 1.00]
```

RULE #5 priority 50 -

```
IF -----
(1) the part size is "larger than stock" [threshold 0.201]
THEN -----
(1) part process is "fabricate superpart (joining process)" [certainty 1.001]
```

RULE #6 priority 50 -

```
IF -----
(1) the part material is alum [threshold 0.20]
THEN -----
(1) part thickness alum = <part 1 mat'l thickness to be cut (in)> [certainty 1.00]
ELSE -----
(1) part thickness alum = 0 [certainty 1.00]
(2) and part section modulus alum = 0 [certainty 1.00]
```

RULE #7 priority 50 -

```
I F -----
(1) the part material is steel [threshold 0.20]
THEN -----
(1) part thickness steel = <part 1 mat'l thickness to be cut (in)> [certainty 1.00]
ELSE -----
(1) part thickness steel = 0 [certainty 1.00]
(2) and part section modulus steel = 0 [certainty 1.00]
```

RULE #8 priority 50 -

```
IF -----
(1) the part process is "cut process" [threshold 0.20]
(2) and the part length (ft) <= <cut process 1 cut part length max (ft)> [threshold 0.20]
(3) and the part width (ft) <= <cut process 1 cut part width max (ft)> [threshold 0.20]
(4) and the part depth (in) <= <cut process 1 cut part depth max (in)> [threshold 0.20]
(5) and the part cut dimensions accuracy requirement (in) >= <cut process 1 cut accuracy (in)> [threshold 0.20]
```

- (6) and the part thickness Steel <= <cut process | mat'l cut thickness max, steel (in)> [threshold 0.20]
- (7) and the part thickness alum <= <cut process | mat'l cut thickness max, alum (in)> [threshold 0.20]
- (6) and the part hole cut diameter (in) <= <cut process | hole diameter max (in)> [threshold 0.20]
- (9) and the part angle max var. from 90 deg <= <cut process | angle cut max (deg)> [threshold 0.20]
- (10) and the part cut configuration is <cut process | cut configuration> [threshold 0.20]
- (11) and the part max cut length (ft) <= <cut process | cut length max (ft)> [threshold 0.20]

THEN

- (1) part cut method is ObjectName(<cut process>) [certainty
- (2) and part cut routing code is <cut process | cut routing code> [certainty 1.00]
- (3) and part cut location is <cut process | cut location> [certainty 1.00]

RULE #9 priority 50 -

IF

- (1) the part process is "form process" [threshold 0.20]
- (2) and the part length (ft) <= <form process | forming part length max (ft)> [threshold 0.20]
- (3) and the part width (ft) <= <form process | forming part width max (ft)> [threshold 0.20]
- (4) and the part depth (in) <= <form process | forming part depth max (in)> [threshold 0.20]
- (5) and the part roll radius accuracy requirement (in) >= <form process | form accuracy (in. radius)> [threshold 0.20]
- (6) and the part section modulus steel <= <form process | section modulus max, steel (in^3)> [threshold 0.20]
- (7) and the part section modulus alum <= <form process | section modulus max, alum (in^3)> [threshold 0.20]
- (8) and the part outside radius (in) >= <form process | outside radius min (in)> [threshold 0.20]
- (9) and the part roll degrees <= <form process | Roll Degrees Max> [threshold 0.20]
- (10) and the part web h/t <= <form process | web h/t max> [threshold 0.20]

THEN

- (1) part forming method is ObjectName(<form process>) [certainty 1.001]
- (2) and part forming routing code is <form process | forming routing code> [certainty 1.00]
- (3) and part forming location is <form process | forming location> [certainty 1.00]

RULE #10 priority 50 -

IF

- (1) the part process is "edge prep process" [threshold 0.20]
- (2) and the part length (ft) <= <edge prep process | edge prep part length max (ft)> [threshold 0.20]
- (3) and the part width (ft) <= <edge prep process | edge prep part width max (ft)> [threshold 0.20]
- (4) and the part depth (in) <= <edge prep process | edge prep part depth max (in)> [threshold 0.20]
- (5) and the part max bevel angle required <= <edge prep process | Bevel Degrees Max> [threshold 0.20]
- (6) and the part thickness steel <= <edge prep process | edge prep thickness max, steel (in)> [threshold 0.20]
- (7) and the part thickness alum <= <edge prep process | edge prep thickness max, alum (in)> [threshold 0.20]
- (8) and the part max edge prep length (ft) <= <edge prep process | edge prep length max (ft)> [threshold 0.20]
- (9) and the part bevel configuration is <edge prep process | bevel configuration> [threshold 0.20]

THEN

- (1) part edge prep method is ObjectName(<edge prep process>) [certainty 1.00]
- (2) and part edge prep routing code is <edge prep process | edge prep routing code> [certainty 1.00]
- (3) and part edge prep location is <edge prep process | edge prep location> [certainty 1.00]

RULE #11 priority 50 -

IF

- (1) the part type is plate [threshold 0.20]

THEN

- (1) part web h/t = 0 [certainty 1.00]
- (2) and part mat'l thickness to be cut (in) = <part | depth (in)> [certainty 1.00]

RULE #12 priority 50 -

IF

- (1) the part type is shape [threshold 0.20]

THEN

- (1) part web h/t = <part | depth (in)> * .94 / <part | web thickness (in)> [certainty 1.00]
- (2) and part mat'l thickness to be cut (in) = <part | flange thickness (in)> [certainty 1.00]

APPENDIX C

System Listing of Inference Process Part #1

```

- - - backward inference (all goals) - - -
attempting to satisfy goal 'part process'
full testing rule 1 - targets: 'part'
    attempting to satisfy goal 'part shape'
        getting a value from the user for part shape
        attempting to satisfy goal 'part shape'
acting -true- on rule 1
part process is form process [certainty 1.00]
full testing rule 2 - targets: 'part'
    attempting to satisfy goal 'part edge/end preparation'
        getting a value from the user for part edge/end preparation
acting -true- on rule 2
part process is edge prep process [certainty 1.00]
full testing rule 3 - targets: 'part'
    attempting to satisfy goal 'part size'
        getting a value from the user for part size
acting -true- on rule 3
part process is cut process [certainty 1.00]
full testing rule 4 - targets: 'part'
    attempting to satisfy goal 'part size'
acting -false- on rule 4
full testing rule 5 - targets: 'part'
    attempting to satisfy goal 'part size'
acting -false- on rule 5
attempting to satisfy goal 'part edge prep method'
full testing rule 10 - targets: 'part' 'Flame Plane 1'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
        getting a value from the user for part length (ft)
    attempting to satisfy goal 'Flame Plane 1 edge prep part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
        getting a value from the user for part width (ft)
    attempting to satisfy goal 'Flame Plane 1 edge prep part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
        getting a value from the user for part depth (in)
    attempting to satisfy goal 'Flame Plane 1 edge prep part depth max (in)'
acting -false- on rule 10
full testing rule 10 - targets: 'Part WC Plasma'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'N/C Plasma edge prep part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'N/C Plasma edge prep part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'WC Plasma edge prep part depth max (in)'
acting -false- on rule 10
full testing rule 10 - targets: 'part' 'edge planer'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'edge planer edge prep part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'edge planer edge prep part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'edge planer edge prep part depth max (in)'
    attempting to satisfy goal 'part max bevel angle required'
        getting a value from the user for part max bevel angle required
    attempting to satisfy goal 'edge planer Bevel Degrees Max'
    attempting to satisfy goal 'part thickness steel'
        full testing rule 7 - targets: 'part'
            attempting to satisfy goal 'part material'
            getting a value from the user for part material
acting -true- on rule 7
    attempting to satisfy goal 'part marl thickness to be cut (in)'
        full testing rule 11 - targets: 'part'
            attempting to satisfy goal 'part type'
            getting a value from the user for part type
acting -false- on rule 11
        full testing rule 12 - targets: 'part'
            attempting to satisfy goal 'part type'
acting -true- on rule 12
    attempting to satisfy goal 'part web thickness (in)'
    attempting to satisfy goal 'part web thickness (in)'
        getting a value from the user for part web thickness (in)
part web h/l is 18.8 [certainty 1.00]
    attempting to satisfy goal 'part flange thickness (in)'
        getting a value from the user for part flange thickness (in)
part marl thickness to be cut (in) is 1.315 [certainty 1.00]
part thickness steel is 1.315 [certainty 1.00]
    attempting to satisfy goal 'edge planer edge prep thickness max. steel (in)'
    attempting to satisfy goal 'part thickness alum'
        full testing rule 6 - targets: 'part'
            attempting to satisfy goal 'part material'
            acting -false- on rule 6
            part thickness alum is 0 [certainty 1.00]
            part section modulus alum is 0 [certainty 1.00]
            attempting to satisfy goal 'edge planer edge prep thickness max. alum (in)'
            attempting to satisfy goal 'part max edge prep length (ft)'
            getting a value from the user for part max edge prep length (ft)
            attempting to satisfy goal 'edge planer edge prep length max (ft)'
            attempting to satisfy goal 'part bevel configuration'
            getting a value from the user for part bevel configuration
            attempting to satisfy goal 'edge planer bevel configuration'
acting -true- on rule 10
part edge prep method is edge planer [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep routing code'
part edge prep routing code is P11 [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep location'
part edge prep location is bay 2 [certainty 1.00]
attempting to satisfy goal 'part edge prep location'
attempting to satisfy goal 'part edge prep routing code'
attempting to satisfy goal 'part cut location'
full testing rule 8 - targets: 'part' 'drill #2'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'drill #2 cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'drill #2 cut part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'drill X2 cut part depth max (in)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' '100 ton punch'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal '100 ton punch cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal '100 ton punch cut part width max (ft)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'band saw'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'band saw cut part length max (ft)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'contour band saw'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'contour band saw cut part length max (ft)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'drill #1'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'drill #1 cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'drill #1 cut part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'drill #1 cut part depth max (in)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'Flame Plane 1'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'Flame Plane 1 cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'Flame Plane 1 cut part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'Flame Plane 1 cut part depth max (in)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'Flame Plane 2'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'Flame Plane 2 cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'Flame Plane 2 cut part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'Flame Plane 2 cut part depth max (in)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'hydraulic band saw'
    attempting to satisfy goal 'part process'
    attempting to satisfy goal 'part length (ft)'
    attempting to satisfy goal 'hydraulic band saw cut part length max (ft)'
    attempting to satisfy goal 'part width (ft)'
    attempting to satisfy goal 'hydraulic band saw cut part width max (ft)'
    attempting to satisfy goal 'part depth (in)'
    attempting to satisfy goal 'hydraulic band saw cut part depth max (in)'
    attempting to satisfy goal 'part cut dimensions accuracy requirement (in)'
    getting a value from the user for part cut dimensions accuracy requirement (in)
    attempting to satisfy goal 'hydraulic band saw cut accuracy (in)'

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attempting to satisfy goal 'part thickness steel'
 attempting to satisfy goal 'hydraulic band saw mart cut thickness max. steel (in)'
 attempting to satisfy goal 'part thickness alum'
 attempting to satisfy goal 'hydraulic band saw marl cut thickness max. alum (in)'
 attempting to satisfy goal 'part hole cut diameter (in)'
 getting a value from the user for part hole cut diameter (in)
 attempting to satisfy goal 'hydraulic band saw hole diameter max (in)'
 attempting to satisfy goal 'pad angle max var. from 90 deg'
 getting a value from the user for part angle max var. from 90 deg
 attempting to satisfy goal 'hydraulic band saw angle cut max (deg)'
 attempting to satisfy goal 'part cut configuration'
 getting a value from the user for part cut configuration
 attempting to satisfy goal 'hydraulic band saw cut configuration'
 attempting to satisfy goal 'part max cut length (ft)'
 getting a value from the user for part max cut length (ft)
 attempting to satisfy goal 'hydraulic band saw cut length max (ft)'
 acting -true- on rule a
 part cut method is hydraulic band saw [certainly 1.00]
 attempting to satisfy goal 'hydraulic band saw cut routing code'
 part cut routing code is sw2 [certainly 1.00]
 attempting to satisfy goal 'hydraulic band saw cut location'
 part cut location is bay 1 [certainly 1.00]
 full testing rule a - targets: 'part 'N/C 2-Axis'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal 'N/C OAxis cut part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal 'N/C PAxis cut part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal 'N/C 2-Axis cut part depth max (in)'
 acting -false- on rule a
 full testing rule 6 - targets: 'part 'N/C Plasma'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal 'N/C Plasma cut part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal 'N/C Plasma cut part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal 'N/C Plasma cut part depth max (in)'
 acting -false- on rule a
 full testing rule 6 - targets: 'part 'shear'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal 'shear cut part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal 'shear cut part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal 'shear cut part depth max (in)'
 acting -false- on rule a
 attempting to satisfy goal 'part cut routing code'
 attempting to satisfy goal 'part cut method'
 attempting to satisfy goal 'part forming location'
 full testing rule 9 - targets: 'part '12 Foot Roll'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '12 Foot Roll forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '12 Foot Roll forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '12 Foot Roll forming part depth max (in)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '250 Ton Press'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '250 Ton Press forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '250 Ton Press forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '250 Ton Press forming part depth max (in)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '37.5 Ton Press'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '37.5 Ton Press forming part length max (ft)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '60 Ton Cold Press'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '60 Ton Cold Press forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '60 Ton Cold Press forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '60 Ton Cold Press forming part depth max (in)'
 attempting to satisfy goal 'part roll radius accuracy requirement (in)'
 getting a value from the user for part roll radius accuracy requirement (in)
 attempting to satisfy goal '60 Ton Cold Press form accuracy (in. radius)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '600 Ton Press'
 attempting to satisfy goal 'part process'

attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '600 Ton Press forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '600 Ton Press forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '600 Ton Press forming part depth max (in)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part 'Brake Press'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal 'Brake Press forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal 'Brake Press forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal 'Brake Press forming part depth max (in)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '1500 Ton Press'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '1500 Ton Press forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '1500 Ton Press forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '1500 Ton Press forming part depth max (in)'
 attempting to satisfy goal 'part roll radius accuracy requirement (in)'
 attempting to satisfy goal '1500 Ton Press form accuracy (in. radius)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part '2000 Ton Roll'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal '2000 Ton Roll forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal '2000 Ton Roll forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal '2000 Ton Roll forming part depth max (in)'
 acting -false- on rule 9
 full testing rule 9 - targets: 'part 'Frame Bender'
 attempting to satisfy goal 'part process'
 attempting to satisfy goal 'part length (ft)'
 attempting to satisfy goal 'Frame Bender forming part length max (ft)'
 attempting to satisfy goal 'part width (ft)'
 attempting to satisfy goal 'Frame Bender forming part width max (ft)'
 attempting to satisfy goal 'part depth (in)'
 attempting to satisfy goal 'Frame Bender forming part depth max (in)'
 attempting to satisfy goal 'part roll radius accuracy requirement (in)'
 attempting to satisfy goal 'Frame Bender form accuracy (in. radius)'
 attempting to satisfy goal 'part section modulus sleet'
 full testing rule 7 - targets: 'part'
 attempting to satisfy goal 'part material'
 acting -true- on rule 7
 attempting to satisfy goal 'part marl thickness to be cut (in)'
 getting a value from the user for part section modulus steel
 attempting to satisfy goal 'Frame Bender section modulus max. steel (in³)'
 attempting to satisfy goal 'part section modulus alum'
 attempting to satisfy goal 'Frame Bender section modulus max. alum (in³)'
 attempting to satisfy goal 'part outside radius (in)'
 getting a value from the user for part outside radius (in)
 attempting to satisfy goal 'Frame Bender outside radius min (in)'
 attempting to satisfy goal 'part roll degrees'
 getting a value from the user for part roll degrees
 attempting to satisfy goal 'Frame Bender Roll Degrees Max'
 attempting to satisfy goal 'part web hi?'
 attempting to satisfy goal 'Frame Bender web M max'
 acting -true- on rule 9
 part forming method is Frame Bender [certainly 1.00]
 attempting to satisfy goal 'Frame Bender forming routing code'
 part forming routing code is pr5 [certainly 1.00]
 attempting to satisfy goal 'Frame Bender forming location'
 part forming location is bay 1 [certainly 1.00]
 attempting to satisfy goal 'part forming routing code'
 attempting to satisfy goal 'part forming method'
 - - - forward inference - - -

the part process
 is cul process [certainly 1.00]
 is edge prep process [certainly 1.001]
 is form process [certainly 1.001]

the part edge prep method
 is edge planer [certainly 1.00]

the part edge prep location
 is bay 2 [certainly 1.001]

the part edge prep routing code
 is pll [certainly 1.00]

the part cut location
is bay 1 [certainty 1.00]

the part cut routing code
is sw2 [certainty 1.00]

the part cut method
is hydraulic band saw [certainty 1.001]

the part forming location
is bay 1 [certainty 1.001]

the part forming routing code
is pr5 [certainty 1.001]

the part forming method
is Frame Bender [certainty 1.00]

***** CONCLUSIONS *****

System Listing of Inference Process Part #2

- - - backward inference (all goals) - - -

attempting to satisfy goal 'part process'
full testing rule 1 - targets: 'part'
attempting to satisfy goal 'part shape'
getting a value from the user for part shape
attempting to satisfy goal 'part shape'
acting -unknown- on rule 1
full testing rule 2 - targets: 'part'
attempting to satisfy goal 'part edgeland preparation'
getting a value from the user for part edgeland preparation
acting -true- on rule 2
part process is edge prep process [certainty 1.00]
full testing rule 3 - targets: 'part'
attempting to satisfy goal 'part size'
getting a value from the user for part size
acting -true- on rule 3
part process is cut process [certainty 1.001]
full testing rule 4 - targets: 'part'
attempting to satisfy goal 'part size'
acting -false- on rule 4
full testing rule 5 - targets: 'part'
attempting to satisfy goal 'part size'
acting -false- on rule 5
attempting to satisfy goal 'part edge prep method'
full testing rule 10 - targets: 'part' 'edge planer'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
getting a value from the user for part length (ft)
attempting to satisfy goal 'edge planer edge prep part length max (ft)'
attempting to satisfy goal 'part width (ft)'
getting a value from the user for part width (ft)
attempting to satisfy goal 'edge planer edge prep part width max (ft)'
attempting to satisfy goal 'part depth (in)'
getting a value from the user for part depth (in)
attempting to satisfy goal 'edge planer edge prep part depth max (in)'
attempting to satisfy goal 'part max bevel angle required'
getting a value from the user for part max bevel angle required
attempting to satisfy goal 'edge planer Bevel Degrees Max'
attempting to satisfy goal 'part thickness steel'
full testing rule 7 - targets: 'part'
attempting to satisfy goal 'part material'
getting a value from the user for part material
acting -true- on rule 7
attempting to satisfy goal 'part material thickness to be cut (in)'
full testing rule 11 - targets: 'part'
attempting to satisfy goal 'part type'
getting a value from the user for part type
acting -true- on rule 11
part web h/t = 0 [certainty 1.00]
attempting to satisfy goal 'part depth (in)'
part material thickness to be cut (in) is .75 [certainty 1.00]
full testing rule 12 - targets: 'part'
attempting to satisfy goal 'part type'
acting -false- on rule 12
part thickness steel is .75 [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep thickness max. steel (in)'
attempting to satisfy goal 'part thickness alum'
full testing rule 6 - targets: 'part'
attempting to satisfy goal 'part material'
acting -false- on rule 6
part thickness alum = 0 [certainty 1.00]
part section modulus alum = 0 [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep thickness max. alum (in)'
attempting to satisfy goal 'part max edge prep length (ft)'
getting a value from the user for part max edge prep length (ft)
attempting to satisfy goal 'edge planer edge prep length max (ft)'
attempting to satisfy goal 'part bevel configuration'

getting a value from the user for part bevel configuration
attempting to satisfy goal 'edge planer bevel configuration'
acting -true- on rule 10
part edge prep method is edge planer [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep routing code'
part edge prep routing code is p11 [certainty 1.00]
attempting to satisfy goal 'edge planer edge prep location'
part edge prep location is bay 2 [certainty 1.00]
full testing rule 10 - targets: 'part' 'Flame Plane 1'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal 'Flame Plane 1 edge prep part length max (ft)'
attempting to satisfy goal 'part width (ft)'
attempting to satisfy goal 'Flame Plane 1 edge prep part width max (ft)'
attempting to satisfy goal 'part depth (in)'
attempting to satisfy goal 'Flame Plane 1 edge prep part depth max (in)'
attempting to satisfy goal 'part max bevel angle required'
attempting to satisfy goal 'Flame Plane 1 Bevel Degrees Max'
attempting to satisfy goal 'part thickness steel'
attempting to satisfy goal 'Flame Plane 1 edge prep thickness max. steel (in)'
attempting to satisfy goal 'part thickness alum'
attempting to satisfy goal 'Flame Plane 1 edge prep thickness max. alum (in)'
attempting to satisfy goal 'part max edge prep length (ft)'
attempting to satisfy goal 'Flame Plane 1 edge prep length max (ft)'
attempting to satisfy goal 'part bevel configuration'
attempting to satisfy goal 'Flame Plane 1 bevel configuration'
acting -false- on rule 10
full testing rule 10 - targets: 'part' 'N/C Plasma'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal 'N/C Plasma edge prep part length max (ft)'
attempting to satisfy goal 'part width (ft)'
attempting to satisfy goal 'N/C Plasma edge prep part width max (ft)'
attempting to satisfy goal 'part depth (in)'
attempting to satisfy goal 'N/C Plasma edge prep part depth max (in)'
attempting to satisfy goal 'part max bevel angle required'
attempting to satisfy goal 'N/C Plasma Bevel Degrees Max'
attempting to satisfy goal 'part thickness steel'
attempting to satisfy goal 'WC Plasma edge prep thickness max. steel (in)'
attempting to satisfy goal 'part thickness alum'
attempting to satisfy goal 'N/C Plasma edge prep thickness max. alum (in)'
attempting to satisfy goal 'part max edge prep length (ft)'
attempting to satisfy goal 'N/C Plasma edge prep length max (ft)'
attempting to satisfy goal 'part bevel configuration'
attempting to satisfy goal 'WC Plasma bevel configuration'
acting -true- on rule 10
part edge prep method is NE Plasma [certainty 1.00]
attempting to satisfy goal 'N/C Plasma edge prep routing code'
part edge prep routing code is br2 [certainty 1.00]
attempting to satisfy goal 'WC Plasma edge prep location'
part edge prep location is bay 3 [certainty 1.00]
attempting to satisfy goal 'part edge prep location'
attempting to satisfy goal 'part edge prep routing code'
attempting to satisfy goal 'part cut location'
full testing rule a - targets: 'part' 'drill #2'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal 'drill #2 cut part length max (ft)'
attempting to satisfy goal 'part width (ft)'
attempting to satisfy goal 'drill #2 cut part width max (ft)'
attempting to satisfy goal 'part depth (in)'
attempting to satisfy goal 'drill #2 cut part depth max (in)'
attempting to satisfy goal 'part cut dimensions accuracy requirement (in)'
getting a value from the user for part cut dimensions accuracy requirement (in)
attempting to satisfy goal 'drill #2 cut accuracy (in)'
attempting to satisfy goal 'part thickness steel'
attempting to satisfy goal 'drill #2 man cut thickness max. steel (in)'
attempting to satisfy goal 'part thickness alum'
attempting to satisfy goal 'drill #2 man cut thickness max. alum (in)'
attempting to satisfy goal 'part hole cut diameter (in)'
getting a value from the user for part hole cut diameter (in)
attempting to satisfy goal 'drill #2 hole diameter max (in)'
acting -false- on rule a
full testing rule 8 - largest 'Part '100 ton punch'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal '100 ton punch cut part length max (ft)'
attempting to satisfy goal 'part width (ft)'
attempting to satisfy goal '100 ton punch cut part width max (ft)'
acting -false- on rule a
full testing rule 8 - targets: 'part' 'band saw'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal 'band saw cut part length max (ft)'
acting -false- on rule 8
full testing rule 8 - targets: 'part' 'contour band saw'
attempting to satisfy goal 'part process'
attempting to satisfy goal 'part length (ft)'
attempting to satisfy goal 'contour band saw cut part length max (ft)'
acting -false- on rule a


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acting -false- on rule 9
full testing rule 9 - targets: 'part' 'Brake Press'
  attempting to satisfy goal 'part process'
acting -false- on rule 9
full testing rule 9 - targets: 'part' 'Frame Bender'
  attempting to satisfy goal 'part process'
acting -false- on rule 9
full testing rule 9 - targets: 'Part' '1500 Ton Press'
  attempting to satisfy goal 'part process'
acting -false- on rule 9
full testing rule 9 - targets: 'part' '2000 To" Roll'
  attempting to satisfy goal 'part process'
acting -false- on rule 9
- - - forward inference - - -

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..... CONCLUSIONS

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the part process
  is cut process [certainty 1.00]
  is edge prep process [certainty 1.00]

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the part edge prep method
  is N/C Plasma [certainty 1.00]
  is edge planer [certainty 1.00]

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the part edge prep location
  is bay 3 [certainty 1.00]
  is bay 2 [certainty 1.00]

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the part edge prep routing code
  is br2 [certainty 1.00]
  is pl1 [certainty 1.00]

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the part cut location
  is bay 3 [certainty 1.00]

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the part cut routing code
  is br2 [certainty 1.00]
  is br1 [certainty 1.00]

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the part cut method
  is N/C Plasma [certainty 1.00]
  is N/C 2-Axis [certainty 1.00]

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the part forming location
(no values)

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the part forming routing code
(no values)

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the part forming method
(no values)

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..... CONCLUSIONS



Stochastic Expert Choice in Ship Production Project Management

VIIA-1

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ABSTRACT

Increasingly rapid and often radical changes in both ship design as well as ship production process technology require more frequent selection from among many alternative technologies and operational strategies under condition of uncertainty. A stochastic time variant hierarchical decision process, or expert choice method, is proposed for use under such conditions. Such an approach is particularly relevant to ship production because here technical decisions usually involve large investments, changes in production or operations and often imply or affect strategic change.

Ship production is complex and capital intensive, as manual production and assembly processes are increasingly automated or replaced by robots. In Japan, for example, more than 10,000 robots were introduced into shipbuilding since 1985 alone. Such radical changes and large scale investments involve complex decisions subject to a multitude of internal and external factors, their associated uncertainties and consequent risk.

Management decisions in ship production often involve several parties, each with its own agenda. Similarly, each will usually attempt to maximize satisfaction with the decision in terms of one or more objectives, which would be affected by the decision.

Achievement of different, often contradicting or conflicting objectives, by different alternative decisions in turn may be influenced by external factors, such as market demand, import prices, labor contracts, government regulations, and environmental constraints. Similarly, endogenous factors such as available credit or existing facilities may affect the contribution of alternatives to the objectives of concern.

Shipbuilders have traditionally delayed major change decisions until the last moment and often until it was too

late to solve a problem. The reason was largely risk aversiveness of shipyard management, an unfortunate attitude in an industry subject to large uncertainties and risks.

Expert choice, or the analytic hierarchical process (AHP), offers an approach which allows consideration of all the factors, as well as the risk attitudes of the decision makers and others involved. The basic AHP method was modified to permit consideration of the probabilities associated with hierarchical relationships of factors and decision makers. AHP is further suggested to include the effect of time on the determination of the risk, and time dependence of the outcome of alternative decisions. Thereby AHP permits determination of not only the most effective choices, but also timing of complex decisions met so frequently in ship production project management.

INTRODUCTION

Most decisions, particularly management decisions in ship production, involve multiple objectives and various alternatives. The performance of alternative decisions in terms of their contribution to the objectives often requires consideration of several levels of factors.

Considering a decision for a new welding process, for example, the first level of choices may be among fully automated, semi-automated, or manual and a number of brand or models in each category. Objectives may include welding costs, weld quality, labor skill, work environment and pollution, capacity, expandability, and more.

The next level, welding costs, may have to be divided into capital and operating or fixed, variable, average, and marginal costs. To relate the performance of decision alternatives to such objectives, intermediate factors such as power and material consumption, rate of production, and more must be introduced.

Similarly, they may find that for a particular choice, output or production rate may affect quality and therefore performance relating to one objective measure, say quality, may well be affected by performance relating to another objective, such as operating costs. This type of decision problem is most effectively represented as a hierarchy shown in Figure 1, where each alternative contributes in some way to factors which in turn impact on performance measures which establish the value of the various objectives.

The different objectives in such a multi-objective decision problem usually have a relative importance or comparative weight for the decision makers. In this paper, the analytic hierarchy process, first suggested by Saaty (1), is applied to ship production project decision problems, and expanded to handle consideration of uncertainty and risk.

ANALYTIC HIERARCHICAL DECISION MODELS

Ship production project management involves, among others, decisions such as choice of production and assembly processes to be used, and of equipment or material to be procured for a particular ship production project.

Such decision processes usually involve one or more decision makers, several often conflicting or even contradictory objectives, multiple performance measures, and various choices. Choices may be unique and independent of timely time variant in terms of their availability, performance, or cost. Similarly, certain risks may be associated with each choice and the weight decision makers place on different objectives may also be uncertain within defined limits.

Assuming a decision hierarchy, as defined in Figure 2, consisting of 4 levels with a single decision maker, the shipyards project manager, who has to choose from among several different pumps for a ship under contract.

Objectives can be ship cost, operating efficiency, etc. while performance measures can be pump cost, installation manhours, and pump performance. Each factor at one level is related to each of the factors at the next higher level in turn, using the comparative weight or contribution it makes to the factor at the next higher level. For example, if pumps 1, 2, and 3 are expected to have relative costs of 1, 1.5, and 2 compared to Pump 1, respectively, and pump 3 is expected to be twice as expensive as pump 2, then information is related by a comparative weight (relative cost) matrix of Pump alternatives with respect to procurement costs shown in Figure 3.

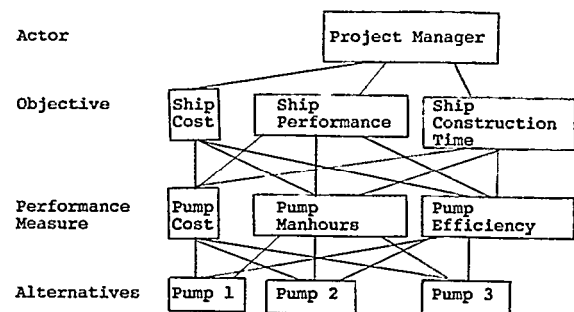


FIGURE 2 - Pump Selection Problem

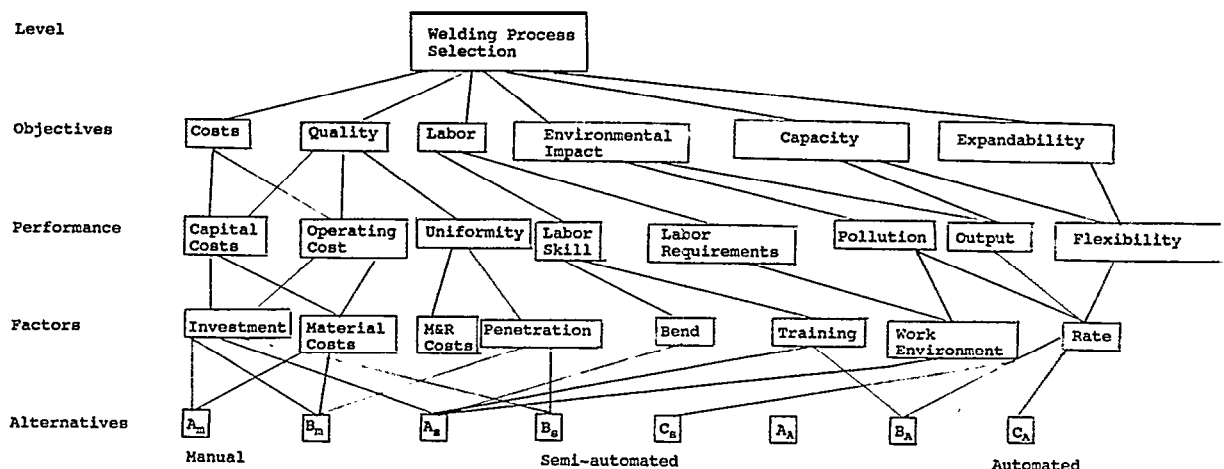


FIGURE 1 - Simple Hierarchical Decision Problem in Shipbuilding

		Pump		
		1	2	3
Pump	1	1	3/2	2
	2	2/3	1	2
	3	1/2	1/2	1

Fig. 3 Pump Procurement Cost Comparison Matrix

There may be some inconsistency in such comparative weighting. This though is easily determined by consistency analysis as shown later in this article. Similar comparison matrices can be drawn up for the pumps with respect to the other factors at the next level (performance measure) as follows.

		Pump		
		1	2	3
Pump	1	1	1/2	1/2
	2	2	1	1
	3	2	1	1

Fig. 4 Comparative Weights with Respect to Installation Manhours

		Pump		
		1	2	3
Pump	1	1	3	2
	2	1/3	1	1/2
	3	1/2	2	1

Fig. 5 Comparative Weights with Respect to Pump Efficiency

Next, each of the performance measures relates to each of the objectives in turn, and finally assumes the relative weight or importance the shipyard decision maker plans on these objectives (ship cost, ship performance, and construction time). As a result, we obtain 3 (3x3) comparative weighting matrices between each of the three lower levels and one (3x3) matrix relating the second (objective) level of the matrix to the shipyard decision maker. The purpose of this analysis is to determine the optimum choice of the shipyard decision maker considering all the comparative weights or rankings.

To obtain the weights of each

alternative with respect to a performance measure, a logarithmic least square or eigenvector method is used. The latter computes the principal right eigenvector of each matrix which can be shown to represent the weight of each alternative with respect to the performance measure considered, and is usually preferred.

The weights are usually obtained as pairwise comparative weights by judgement or from actual data. For example, if fuel consumption and reliability are two factors against which two machines, A and B, are to be weighted, and A consumes on average 50% more fuel than B, then the comparative weighting matrix is shown in Figure 6.

	A	B
A	1	3/2
B	2/3	1

Fig. 6 Comparative Weights of Machines A and B Against Fuel Consumption

Comparative reliability may be estimated from interviews, or from Delphi type experiments which may give results that are not fully consistent such as (Figure 7)

	A	B
A	1	5/2
B	2	1

Fig. 7 Comparative Weights of Machines A and B Against Reliability

DETERMINISTIC ANALYTIC MODEL SOLUTION METHODS

If A is a matrix of the form

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{bmatrix} \quad (1)$$

where a_{ij} is the comparative weight of i compared to j with respect to the factor against which their performance is measured, and w_i and w_j are the priority weights of i and j , then $w_i/w_j = a_{ij}$ for all pairs i, j .

In the ideal case with complete consistency, all $a_{ij} = w_i/w_j = a_{ij} = w_i/w_j = w_i/w_j$ and $a_{ji} = 1/a_{ij} = w_j/w_i$ and $w_i = a_{ij}w_j$ ($i, j=1, 2, \dots, n$) as well as The purpose is to obtain an unbiased vector of the weights of the alternatives

$$w_1 = \frac{1}{n} \sum_{j=1}^n a_{ij} w_j \quad (i, j=1, 2, \dots, n) \quad (2)$$

$i=1, \dots, n$ with respect to each of the factors at the next higher level. Usually $a_{ij} = w_{ji}/w_i$ but perturbations of this ratio will usually occur. If λ_{\max} is the maximum eigenvalue of the matrix A, then

$$\lambda_{\max} = \left(\sum_{j=1}^n a_{ij} w_j \right) / w_i \quad (\text{all } i) \quad (3)$$

The eigenvector of A can be obtained in different ways, to determine the weights of the i th with respect to the factor at the next level. An approximate, yet simple, way is to sum the entries a_{ij} in each row and divide by the sum of the rows, or for

$$A = \begin{bmatrix} 1 & a_{12} \\ a_{21} & 1 \end{bmatrix} = \begin{bmatrix} (1+a_{12}/S) \\ (1+a_{21}/S) \end{bmatrix} \quad (4)$$

$$\text{where } S = (2 + a_{12} + a_{21})$$

As the $a_{ij} = 1/a_{ji}$ it is necessary to measure if the values a_{ij} and a_{ji} (all i, j) are consistent. This can be performed by using the eigenvector (or the maximum eigenvalue λ_{\max}) to measure consistency of the matrix A. $(\lambda_{\max} - n) / (n-1) =$ "consistency index" is a useful measure of consistency. Using a Random Inconsistency Index (R.I.I.) developed by Saaty [1] computed by random tests where R-I. is found to be

n	R I
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

We can now determine the consistency ratio C.R. = C.I./R.I. which should have a value of C.R. ≤ 0.1 for acceptable consistency. The C.R. > 0.1 judgements on comparative weights may have to be revised.

A more accurate way to compute the priority or eigenvector $[w_i]$ is to raise A to increasing powers of K and then normalizing the result:

$$P^K = \lim_{K \rightarrow \infty} A^K e / e^T A^K e$$

where $e = (1, \dots, 1)$ and for $K = 1$

$$P^1 = A e / e^T A e$$

and second estimate

$$P^2 = A^2 e / e^T A^2 e$$

This is continued until iteration K when the process converges and the normalized weights of w_i remain constant from iteration to iteration.

DETERMINISTIC DECISION EXAMPLE IN SHIP PRODUCTION

Assume a very simple three stage problem, as shown in Figure 8, where the production manager and controller are assumed to have relative weights of 1/3 to 2/3 respectively, the pairwise comparative weights of A and B, use of building ways and built-in dock, with respect to C, D, and E and their priority vectors are,

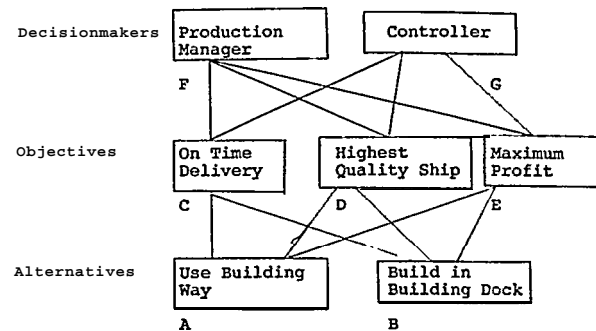


FIGURE 8

A and B with respect to C - On-time delivery

	A	B	Priority Vector
A	1	1/2	1/3
B	2	1	2/3

A and B with respect to D - Highest Quality Ship

	A	B	Priority Vector
A	1	3/2	25/39
B	2/5	1	14/39

A and B with respect to E - Maximum Profit

	A	B	Priority Vector
A	1	4/3	14/25
B	1/2	1	9/25

Next we obtain the priority vectors of C, D, and E with respect to F, the production manager, and with respect to E, the controller, as follows.

With respect to F

	C	D	E	Priority Vector
C	1	5/4	1/2	33/133
D	2/3	1	2/3	28/133
E	2	3	1	72/133

And with respect to G

	C	D	E	Priority Vector
C	1	1	2	240/574
D	1	1	3/2	210/574
E	2/5	2/3	1	124/574

The priority vectors for F or G are obtained by multiplying the matrix of priority vectors of A and B with respect to C, D, and E by the priority vectors of C, D, E with respect to F and G respectively viz:

Priority Vector with respect to production manager:

$$\begin{matrix} & \begin{matrix} C & D & E \end{matrix} \\ \begin{matrix} A \\ B \end{matrix} & \begin{bmatrix} 1/3 & 25/39 & 14/25 \\ 2/3 & 14/39 & 9/25 \end{bmatrix} \end{matrix} \begin{bmatrix} 33/133 \\ 28/133 \\ 72/133 \end{bmatrix} = \begin{bmatrix} 0.52 \\ 0.48 \end{bmatrix}$$

and Priority Vector with respect to controller

$$\begin{matrix} & \begin{matrix} C & D & E \end{matrix} \\ \begin{matrix} A \\ B \end{matrix} & \begin{bmatrix} 1/3 & 25/39 & 14/25 \\ 2/3 & 14/39 & 9/25 \end{bmatrix} \end{matrix} \begin{bmatrix} 240/574 \\ 210/574 \\ 124/574 \end{bmatrix} = \begin{bmatrix} 0.495 \\ 0.505 \end{bmatrix}$$

With the relative weight (or importance) of the two decision makers of 1/3 and 2/3

respectively, the final priority weights of decision alternatives A and B are therefore

$$\begin{aligned} 1/3 \times 0.520 + 2/3 \times 0.480 &= 0.493 \\ 1/3 \times 0.495 + 2/3 \times 0.505 &= 0.507 \end{aligned}$$

In other words, alternative B has a slightly higher weight.

STOCHASTIC EXPERT CHOICE DECISION MAKING

In ship production, the pairwise comparative weights are often quite uncertain and, instead of unique pairwise comparative weights, one can often obtain only probabilistic or conditional probabilistic pairwise weight comparisons. In the simplest case a range of pairwise comparison weights are given, a_{ijmax} and must then obtain the consistent range of a_{ijmax} and a_{ijmin}

Conversely, the a_{ij} may be conditioned on some weight a_{ke} . If a range () is given, it is usually possible to determine the consistent range of $a_{ijmax} - a_{ijmin}$ or vice versa. Using the resulting extreme consistent values, the range of values of the priority weights $w_{imax} - w_{imin}$ ($i=1....n$) for all the matrices in the hierarchy can be determined, and ultimately the range of the priority weights of the alternatives is a function of the characteristics of the hierarchy.

In a simple trivial example, it may be assumed that the comparative weight of the production manager is at least one quarter, but no more than 2/5 ths in relation to the controller and that the controller's weight is at least one half but no more than 3/4 ths in relation to the production manager.

After checking for consistency, one could now determine the range of comparative weights of the two decision alternatives between the extreme values obtained. Using standard statistical techniques, one could also determine the expected comparative weight.

The same method can be used when there are ranges in comparative weights at more than one level in the hierarchy.

CONCLUSION

Expert choice hierarchical decision models are useful tools for the solution of complex multi-criteria, multi-level decision problems which abound in ship production. The simple examples presented may seem trivial but the method proves to be quite powerful in the solution of large, full-scale real world problems.

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Implementation of PC-Based Project Management in an Integrated Planning Process

VIIA-2

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ABSTRACT

This paper describes the progress made and lessons learned by National Steel and Shipbuilding (NASSCO) on National Ship Research Program (NSRP) task N8-91-6 "Implementation of PC-Based Project Management in an Integrated Planning Process." NASSCO is developing a computer-based model which will serve as a tool to assist planning organizations in developing, updating, and revising Master Production Schedules (MPS) as well as manning and facility utilization reports.

GLOSSARY

The following definitions are provided to clarify usage within this paper. They are not meant to imply any type of industry standard.

MASTER PRODUCTION SCHEDULE (as defined by the American Production and Inventory Control Society Dictionary)"... the anticipated build schedule for those selected items assigned to the master scheduler..." [1]

BLOCK- A structural assembly which will be erected singly or as part of a grand block

GRAND BLOCK- Two or more blocks that have been joined into a single unit prior to erection.

LONG RANGE FORECAST- Needs implied by schedules over a two to three year time span. This forecast will show manning and capacity needs of a project from start of construction to launch.

SHORT TERM REQUIREMENTS- Needs implied by schedules over a two to three month time span. The requirements are used for regularly updated, detailed manpower and facility utilization planning.

SYSTEM DEVELOPMENT PHILOSOPHY

The purpose of scheduling is to optimize the use of resources so that the overall production objectives are met. Scheduling involves the assignment of dates to specific tasks. Machine breakdowns, absenteeism, quality and performance problems, material shortages, and other factors complicate the manufacturing environment. Hence, the assignment of a date does not ensure that the work will be performed at that time. [2] A scheduling system should have the ability to adapt schedules to reflect changes in the manufacturing environment.

An effective model for use in production scheduling must reflect the strategy by which the ship will be built. These strategies establish the activity durations, resource utilization, and relationships to be used by the Integrated Production Planning System. The system models discussed in this paper are based upon the strategy sheets described in table 1. (Note: these strategy sheets are illustrated in the System's Usage section of this paper.) All strategy sheets are reviewed, discussed, and approved prior to model development.

Even if a PC-based model of the production process was not developed, creation of the documents described above is a useful tool. By bringing together the various production and support groups for the strategy review process, the build strategies will often be substantially improved.

In addition to the strategy sheets, it is also necessary to develop a coding system for the work breakdown structure (WBS) and the organizational breakdown structure (OBS). Development of these coding systems allows the data to be grouped in meaningful ways. Schedule information is distributed to all required groups in a format meaningful to that group.

A schedule dictates not only the dates on which various activities occur, but also a specific set of material, engineering, facility utilization, and manning requirements. For a schedule to remain credible, it must account for actual material delivery, engineering drawing issues, facility availability, and manpower availability. This cyclic relationship implies that a credible schedule can be derived only when these factors are considered together.

STRATEGY SHEET	DESCRIPTION
BLOCK BREAKDOWN DIAGRAM	IDENTIFIES BREAKDOWN OF SHIP INTO STRUCTURAL ASSEMBLIES AND SHOWS ASSEMBLIES THAT JOIN TOGETHER PRIOR TO ERECTION.
STRATEGY, DURATION, AND RESOURCE REQUIREMENTS BY BLOCK TYPE	GROUPS BLOCKS INTO SIMILAR TYPES. STRATEGIES, ACTIVITY DURATIONS, AND ACTIVITY RESOURCE REQUIREMENTS ARE GIVEN FOR EACH BLOCK TYPE.
BUILD STRATEGY SHEETS	SHOWS ACTIVITIES TO BE TRACKED BY THE INTEGRATED PRODUCTION PLANNING SYSTEM AND THE RELATIONSHIPS BETWEEN THESE ACTIVITIES FOR EACH BUILD STRATEGY.
ERECTION 'STAR' CHART	SHOWS THE DATE EACH ERECTABLE UNIT IS SCHEDULED TO BE JOINED TO THE SHIP.
GRAND BLOCK STRATEGY SHEETS	SHOWS IN GANTT CHART FORMAT THE STRATEGY BY WHICH THE BLOCKS WILL OUTFIT AND STACK TOGETHER TO FORM THE GRAND BLOCK.
PROCESS LANE STRATEGY SHEETS	SHOWS IN GANTT CHART FORMAT THE FLOW OF BLOCKS THROUGH EACH OF THE DEDICATED PROCESS LANES.

Table 1: Strategy sheet descriptions.

Data are facts concerning objects, events, relationships, and requirements. Information is data that have been organized in a form that is suitable for decision making. The development of a schedule is not an analytically complex task. Development is made complex due to the large volume of data which must be considered when developing schedules. The Integrated Production Planning System transforms the large volume of data which influences schedules into information. The clearest way to convey this information is through graphical displays of schedules, manning and facility utilization data. By showing relevant data in this graphical form, the system should serve as a useful tool in generating and updating the MPS.

SCOPE OF PROJECT

An effective integrated production schedule must consider all activities that go on within a shipyard. However, this does not mean that a single production planning system must model all activities. If an individual system models a well-defined area of the shipyard, this information can be combined with information regarding other areas to develop an overall view of the shipyard system.

The scope of activities to be modeled by the Integrated Production Planning System are listed.

- Fabrication of Steel Parts
- Block Sub-Assemblies (i.e. building of bulkheads and decks from fabricated parts)
- Block Assembly
 - Pre-Blast Outfitting of Blocks
 - Blast and Paint of Blocks
 - Post-Blast Outfitting of Blocks
 - Grand Blocking (joining of blocks before they erect to ship)
 - Block or Grand Block Erection to Ship

The on-board, shop, production service, repair, and non-production activities are not modeled by this system. Schedules and information regarding these activities are developed in parallel with the system. This data is combined with the data developed by the Integrated Production Planning System and is used to provide information regarding the entire shipyard.

The MPS must be coupled to bills of material structured to support the production process. They are not separate issues. A workable interface between the scheduling and material requirement system is vital. Development of this interface is dependent upon both the planning and material systems employed by the yard.

This issue will not be addressed in this paper. However, when an integrated production scheduling system is being developed, the scheduling/materials system interface must be considered.

As with the bills of material, the MPS must be supported by engineering. Engineering specifications and drawings must be scheduled so as to be completed in support of the production and material ordering process. However, the scheduling of these items will not be considered within the scope of this project

SCHEDULE GENERATION SYSTEM OVERVIEW

The flow chart below shows the Integrated Production Planning System's major inputs, outputs, and components. The system consists of four modules which interact to create both the baseline and regularly updated production schedules. The system also generates manning and facility long range and short term requirements.

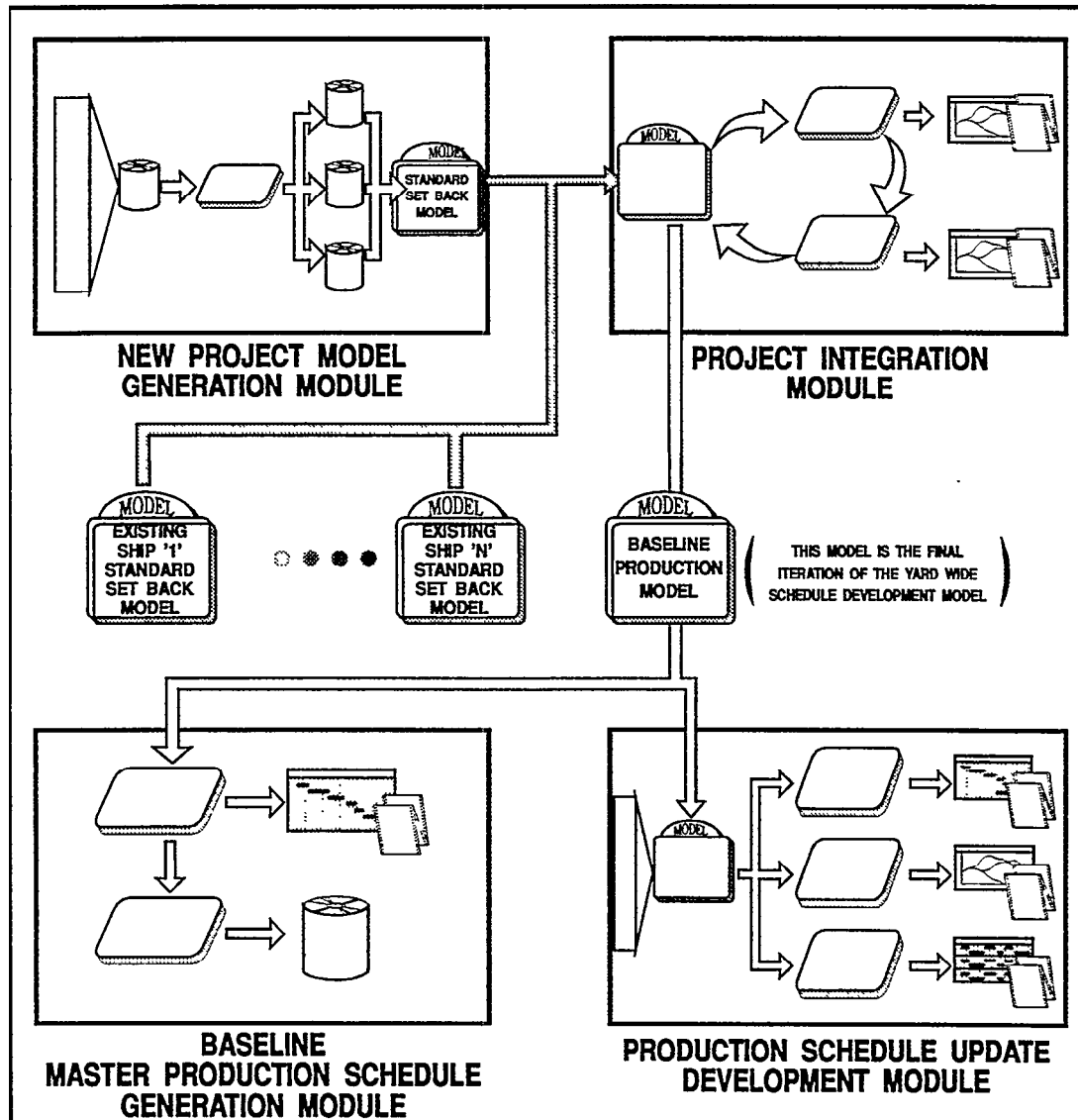


Figure 1 : Integrated Production Planning System Flowchart.

The new project model generation module is shown in figure 2. When a new project (i.e., a ship) is brought into the yard, data is gathered regarding build strategies, activity resource requirements, process lane considerations, and block erection data. All this

information is integrated into a Ship Build Master Data File. This data is passed through the Model Builder Program which creates a Standard Set Back Model for the ship.

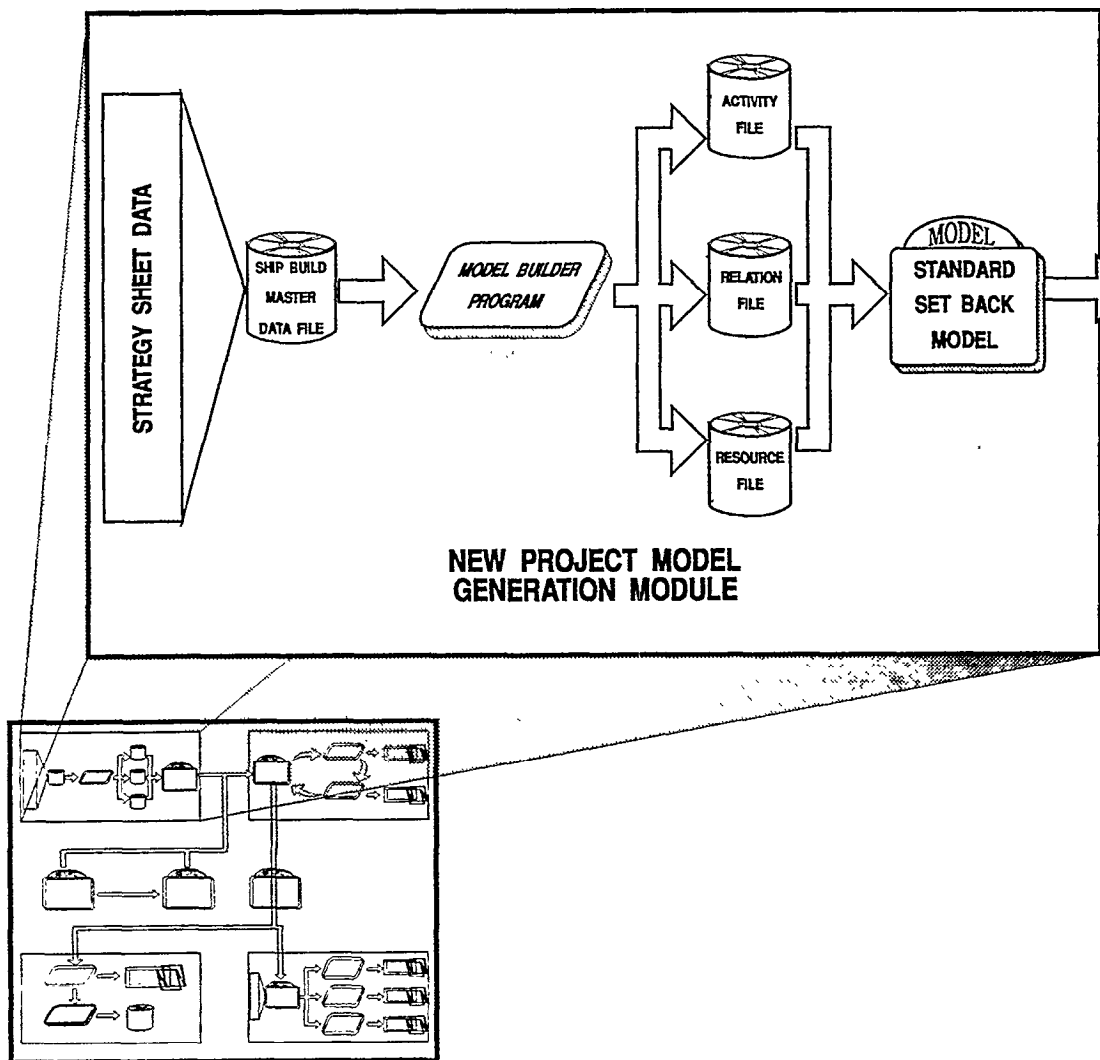


Figure 2 : New Project Model Generation Module.

The project integration module is shown in figure 3. Standard set back models take into account build strategies for only the individual ship. Since all ships are built with common facilities and manpower, leveling the MPS is done with all the projects in the yard considered together. The Standard Set Back Model is combined with the standard set back models of previously scheduled work to create a Yardwide Schedule Development Model. This model is processed to show

the capacity and manpower requirements implied by these schedules. Based upon this information, the model is refined through an iterative process. Capacities and manning implied by the schedule are investigated. Schedules are modified until acceptable capacity utilization and manning are achieved. The final iteration of the model is reviewed and approved by the various department heads. Upon approval, this model becomes the Baseline Production Model.

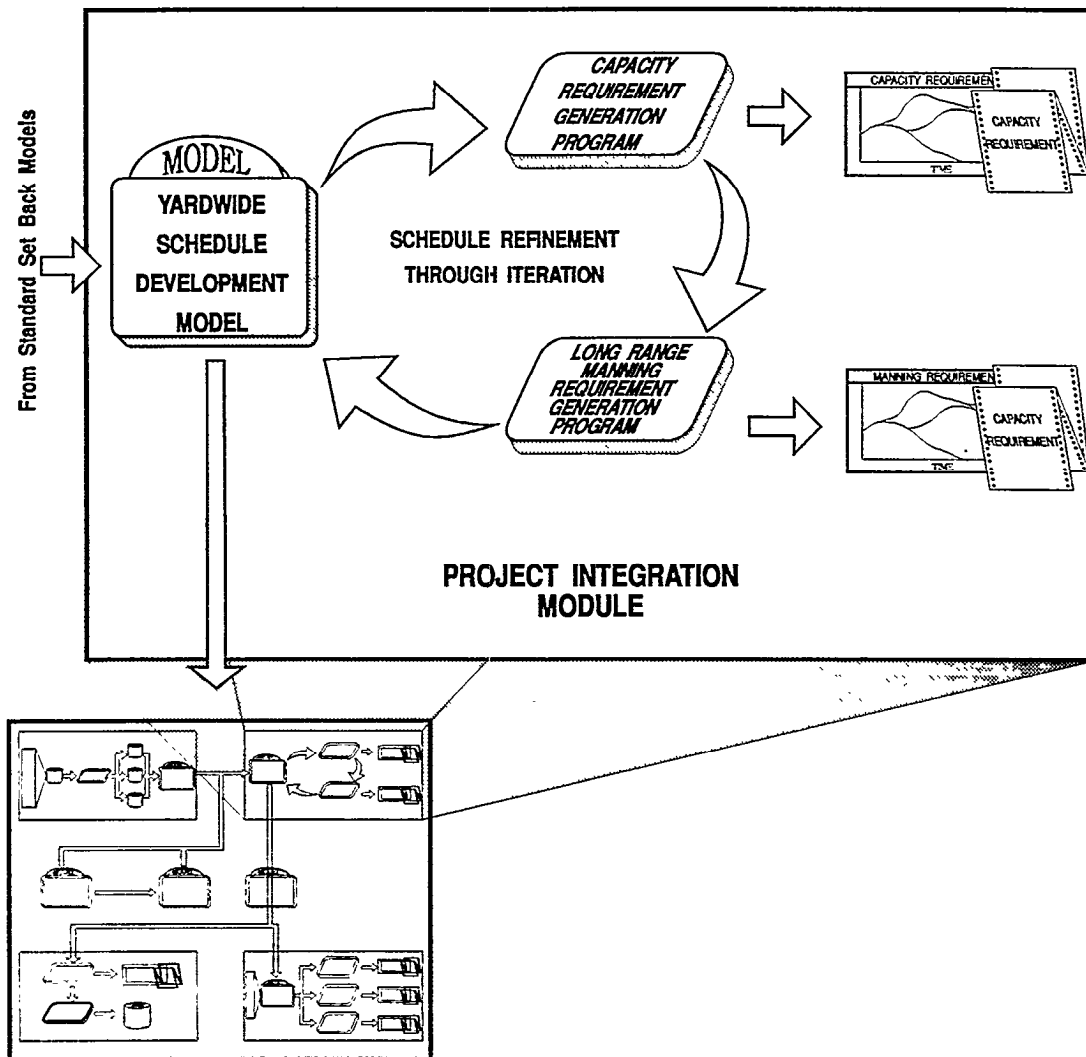


Figure 3 : Project Integration Module.

The baseline master production schedule generation model is shown in figure 4. The Baseline Production Model is used to create and update the master production schedules for each project. The model is also used to create and update a database

which serves as the baseline schedule for the schedule tracking system. The Baseline Production Model is altered only when a new revision of an existing project's schedule is issued.

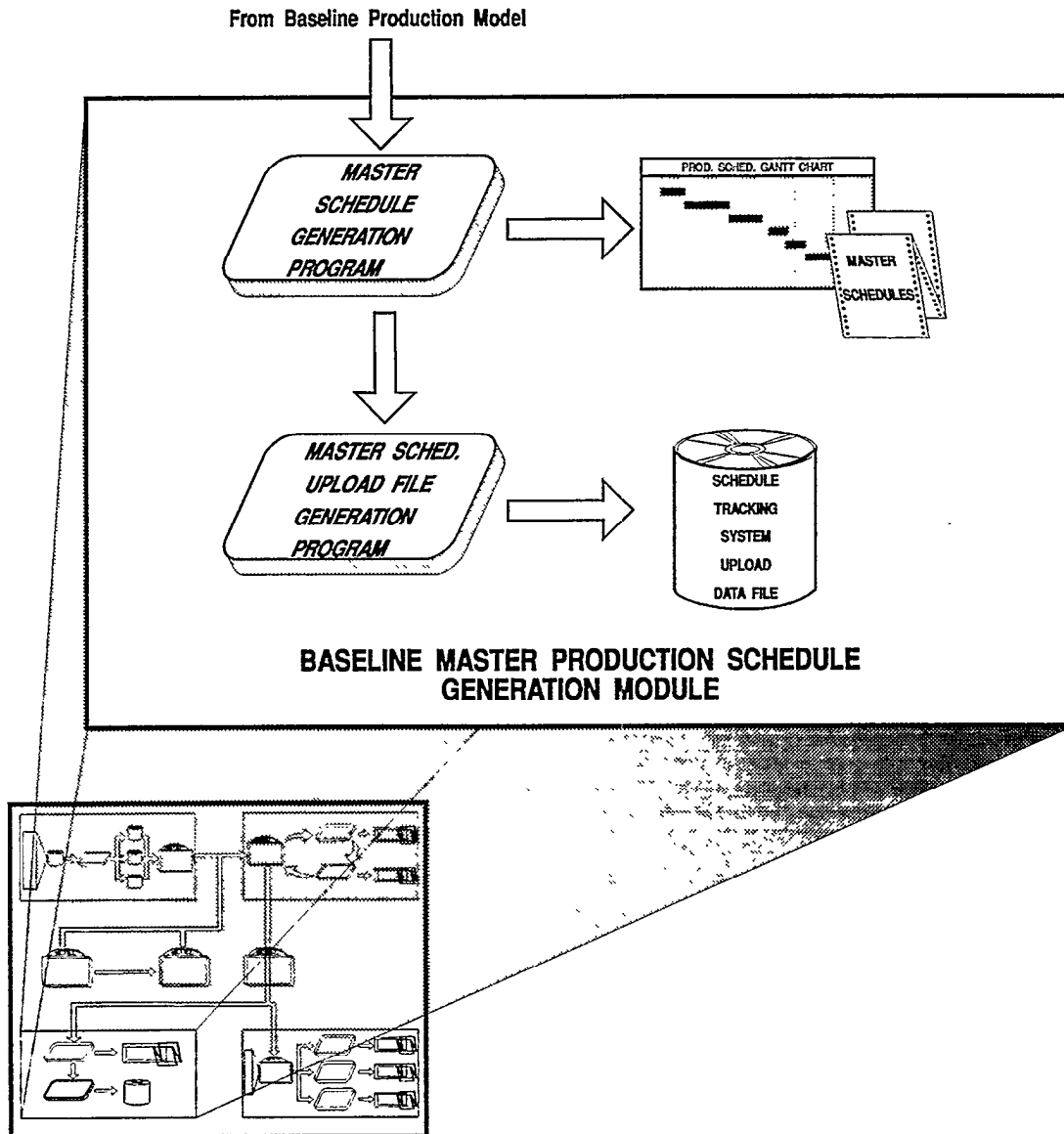


Figure 4 : Baseline Master Production Schedule Generation Module.

The production schedule update development module is shown in figure 5. A copy of the Baseline Production Model is renamed the Production Update Model. This model is updated based on weekly meetings and progress data. The updated model is processed and used to generate regularly issued production schedules,

manning curves, and facility utilization reports (laydown schedules). The production schedules show planned vs. actual and projected progress. The manning curves and facility utilization reports reflect adjustments that have been made from de master schedule to the current production schedule.

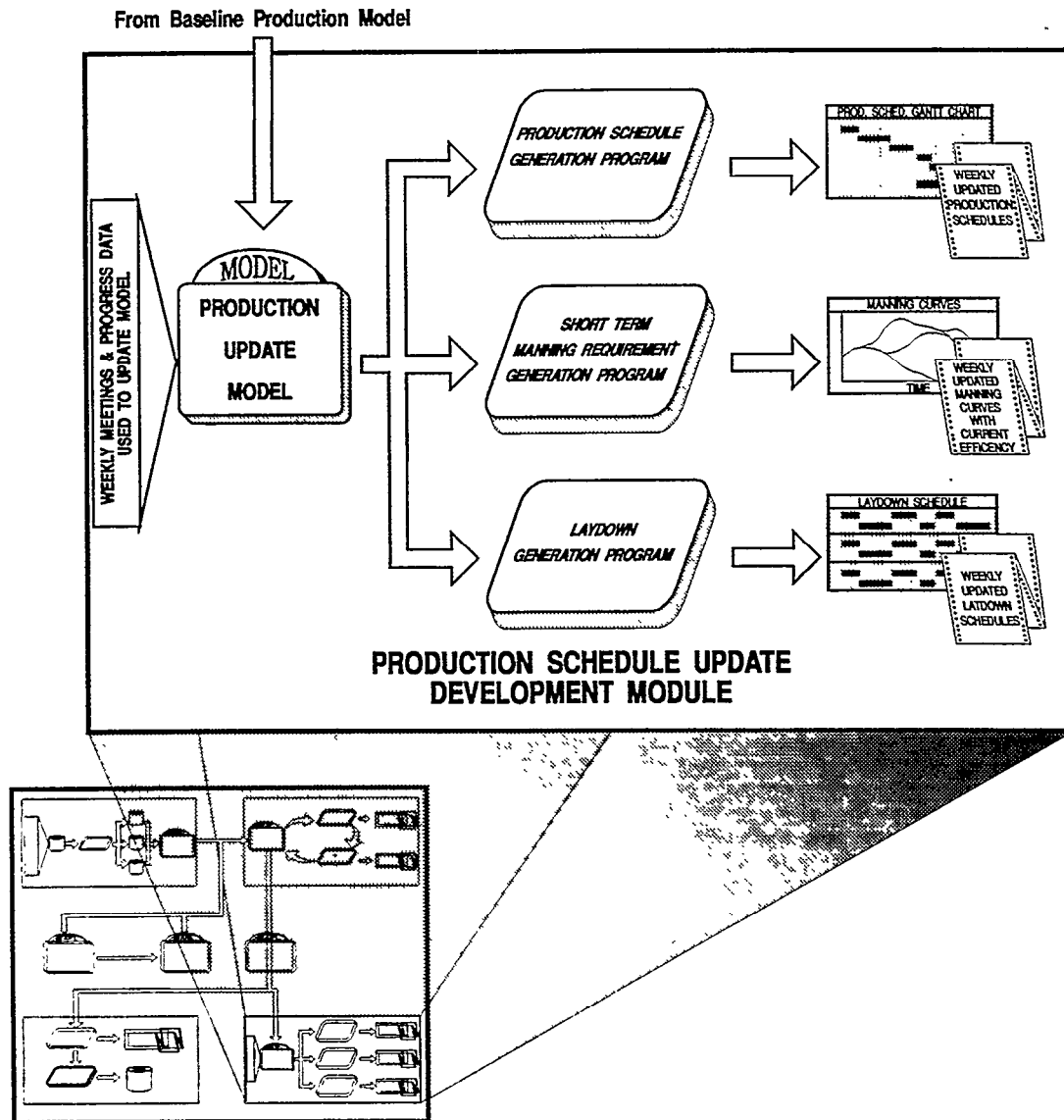


Figure 5 : Production Schedule Update Development Module.

SYSTEM COMPONENTS

As stated earlier, this presentation is only meant to report on the progress of the system to date. The Integrated Production Planning System is still in the process of development. A full report on the system will be available through the NSRP in early 1992. This full report will include hard copies, disk copies, and documentation of all programs written at NASSCO for this project. The report will also include information regarding how to obtain the commercially-available software discussed in the paper.

Open Plan™ Software

The Integrated Production Planning System is built around Welcom Software Technology's Open Plan™ PC-based project management software (hence referred to as the project management software). There are several PC-based project management packages on the market today. One of the advantages of this software is that the software package operates within a dBase™ shell. All of the project management software input and output files are in standard dBase™ format. This allows all pre-processing and post-processing programs built around the project management software to be written in dBase™.

All models shown in the System Overview exist within the project management software framework. The software serves to take data regarding individual activities and creates schedules and resource utilization files. The data regarding individual activities is placed into three separate files. The activity file contains the duration of each activity. Before this file is processed, the only dates in this file are the start or complete date for key events. The relationship file shows the required interaction between various activities. The resource file shows the manning and facility requirements of each activity; The project management software processes these data files and generates all the dates that were not previously defined. These dates are stored to the processed activity file. The software also creates a resource aggregation file. This file shows the utilization of all resources as a function of time. The major inputs and outputs of a project management software model are shown in figure 6.

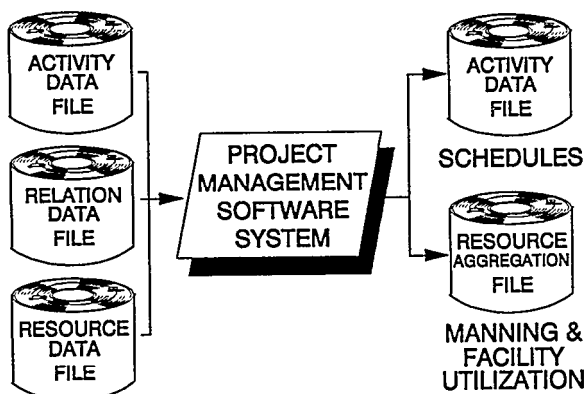


Figure 6 : Project Management Software Input and Output Files.

System Control Program

All of the programs that interact to create the Integrated Production Planning System can be accessed through the System Control Program. As illustrated in figure 7, the program is menu driven and is used to guide the user into and out of the various system functions.

Model Builder Program

The Integrated Production Planning System models the activities associated with the assembly, outfitting, and erection of hull blocks. A scheduling model with sufficient detail to meet the system objectives will be large. A model for a 700' container ship consisted of 3000 activities, 3000 relationships, and 10,000 resource requirements. These numbers will vary depending upon the size and complexity of the vessel. A yardwide integrated planning model is too large to make practical the entering of all relevant data by hand. Using similarities that exist between groups of activities, relationships, and resources a program can be developed that builds a standard set back model for a ship. The Model Builder Program uses block specific data and build strategies by block type. Based on strategy sheet data, the Model Builder Program creates activity, resource, and relationship files in proper format to be used by the project management software.

Capacity Requirement Generation Program

Capacity requirements for each activity are included as a resource when the model is generated. The Capacity Requirement Generation Program uses the yardwide schedule development model's resource aggregation file (created by the project management software) to show resource utilization information in both graphical and tabular form. The resources may be shown singly or grouped according to WBS or OBS.

Long Range Manning Requirement Generation Program

Budgeted hours for each activity are included as resources when the model is generated. The Long Range Manning Requirement Generation Program uses the yardwide schedule development model's resource aggregation file (created by the project management software). The data from this file is combined with manning requirements from other areas of the yard not included in the Integrated Production Planning System to produce manning requirements in both graphical and tabular form. Depending upon how the resource requirement was initially entered into the system, the output may be shown by trade class, area, or any groupings of trade classes or areas. The program also allows for these requirements to be factored up or down to allow for actual production efficiencies.

Master Schedule Generation Program

The Master Schedule Generation Program uses the activity file of the baseline production model (after processing by the project management software). The program takes the activity file and extracts the dates necessary to generate the various master schedules used throughout the yard.

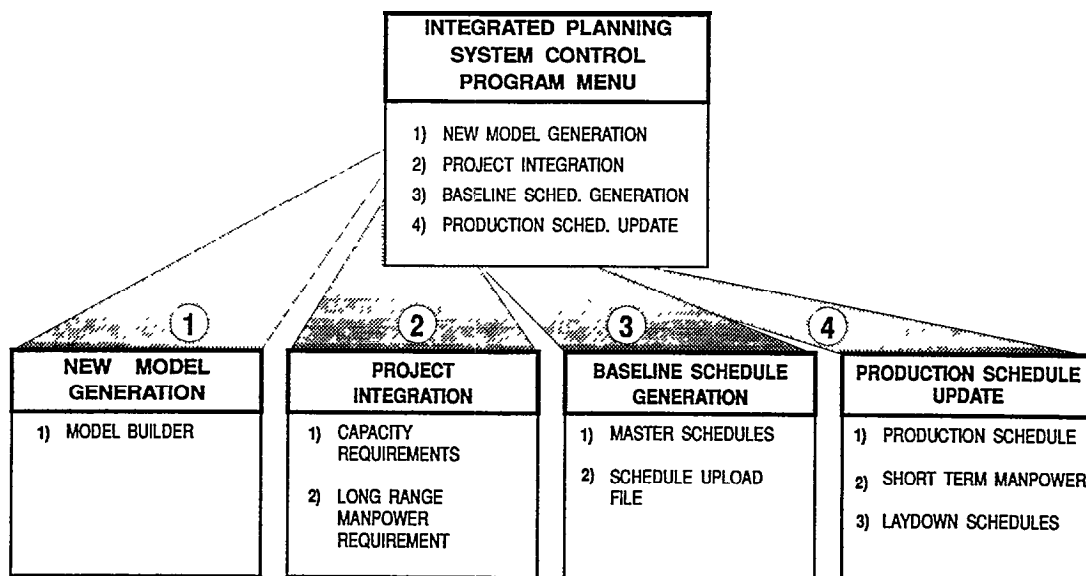


Figure 7 : System Control Program.

Master Schedule Upload File Generation Program

The Master Schedule Upload File Generation Program uses the data files created by the Master Schedule Generation Program. These files are converted to a form so that they may be uploaded into the schedule tracking system database. This allows the schedule tracking system to be rapidly and accurately updated when a change occurs to a master schedule.

Production Schedule Generation Program

The Production Schedule Generation Program uses the activity file of the production update model (after processing by the project management software). The program takes the activity file and extracts the dates necessary to generate the updated production schedules in both graphical and tabular form. These schedules show planned vs. actual dates and projected progress.

Short Term Manning Requirement Generation Program

The Short Term Manning Requirement Generation Program is similar to the Long Range Manning Requirement Generation Program. However, the short term requirements are generated from the resource aggregation file of the production update model rather than the yardwide schedule development model.

Laydown Generation Program

The Laydown Generation Program uses the activity file of the production update model (after processing by the project management software). The program takes the activity file and extracts the dates and laydown locations necessary to develop laydown schedules for each production area in both graphical and tabular form.

SYSTEM USAGE

To demonstrate how the Integrated Production Planning System is used, schedules were developed and progressed for a test case. The test case is the construction of the M/V Well Planned, a small, double-hulled product carrier. The first and most important task in scheduling is the development of a build strategy. The build strategy for the M/V Well Planned is expressed in terms of the documents described in the Systems Development Philosophy section of this report. The strategy sheets for the M/V Well Planned are shown in figures 8 through 15.

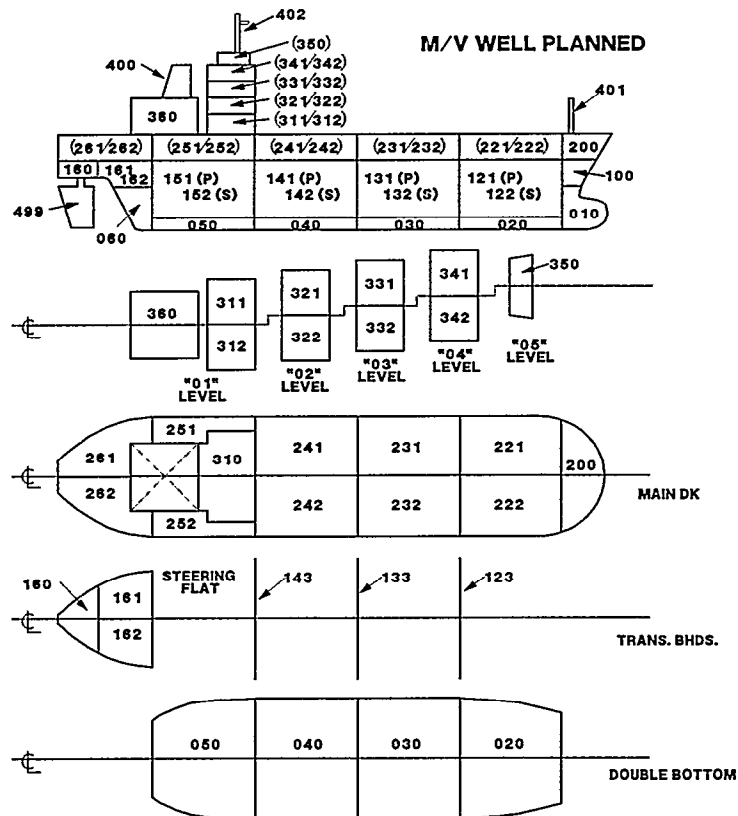


Figure 8 : Block breakdown of M/V WELL PLANNED.

BLK TYPE	BLOCK NUMBERS	BUILD STRAT.	ASSY	PRE-BLAST INVERTED	PRE-BLAST UP RIGHT	BLAST & PAINT	POST BLAST
DOUBLE BOTTOM	020,030 040,050	STANDARD	20 1500	— —	5 250	5 100	5 250
TRANS. BHD.	123, 133 143	STANDARD	15 500	5 150	— —	5 100	5 150
STERN	160,261 262	STANDARD	15 200	10 300	5 150	5 100	5 150
STERN	161, 162	GRAND BLK ASSEMBLY	15 100	— —	— —	— —	— —
MAIN DECK	251,252	STANDARD	15 800	5 200	— —	5 100	5 200
MAIN DECK	221->242	GRAND BLK INVERTED	15 1000	— —	— —	— —	— —
WING	121-> 152	STANDARD	15 800	5 150	— —	5 100	5 150
BOW	200	STANDARD	20 1500	5 125	5 125	5 100	10 125
BOW	010, 100	GRAND BLK UP RIGHT	20 2000	— —	— —	— —	— —
HOUSE	310->350	GRAND BLK POST	15 800	20 800	5 200	5 100	— —
MAST	401,402	SHOP	— —	10 300	— —	5 100	20 700
RUDDER	499	STANDARD	30 1000	— —	— —	5 100	— —
CASTING	360	STANDARD	15 900	10 500	10 500	5 100	10 500
STACK	400	STANDARD	20 1000	— —	10 500	5 100	10 500

Figure 9 : Durations and budgets by block type for M/V WELL PLANNED

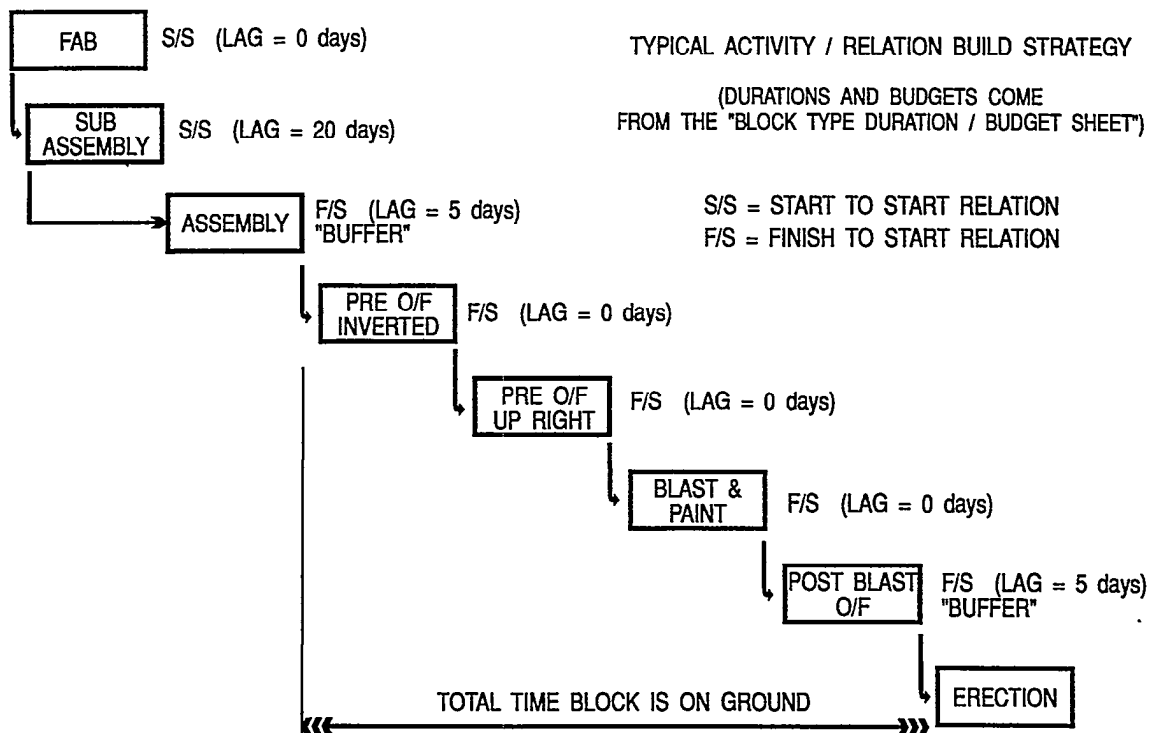


Figure 10 : Activities and relationships for a block with a "Standard" build strategy.

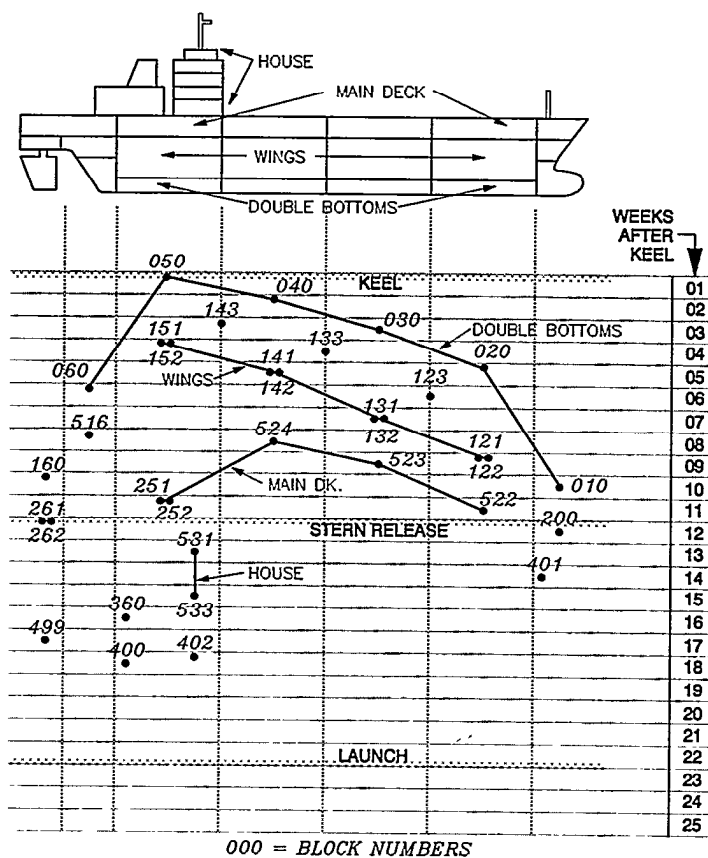


Figure 11 : Erection "star" chart for the M/V WELL PLANNED.

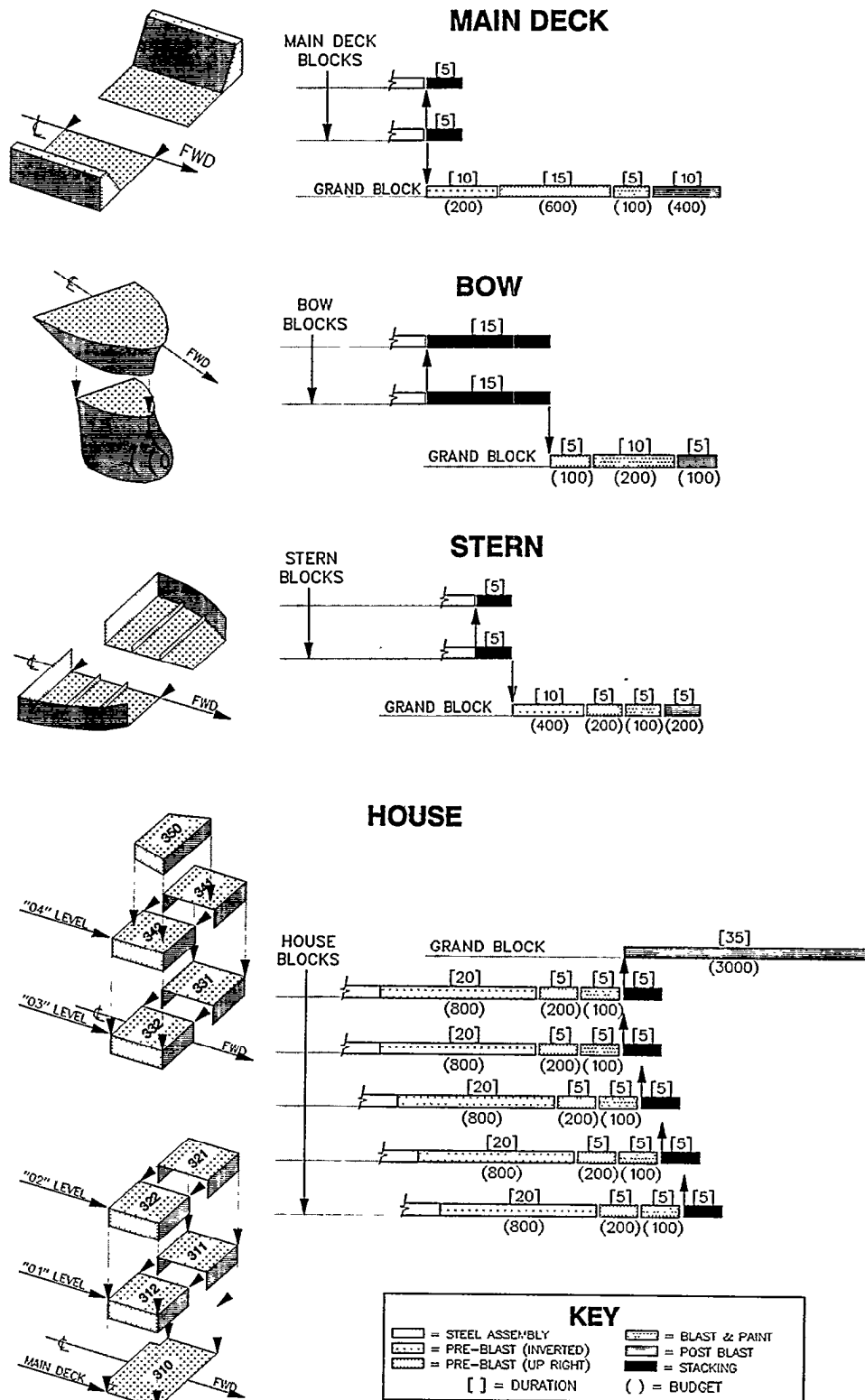


Figure 12: Grand block strategies for M/V WELL PLANNED.

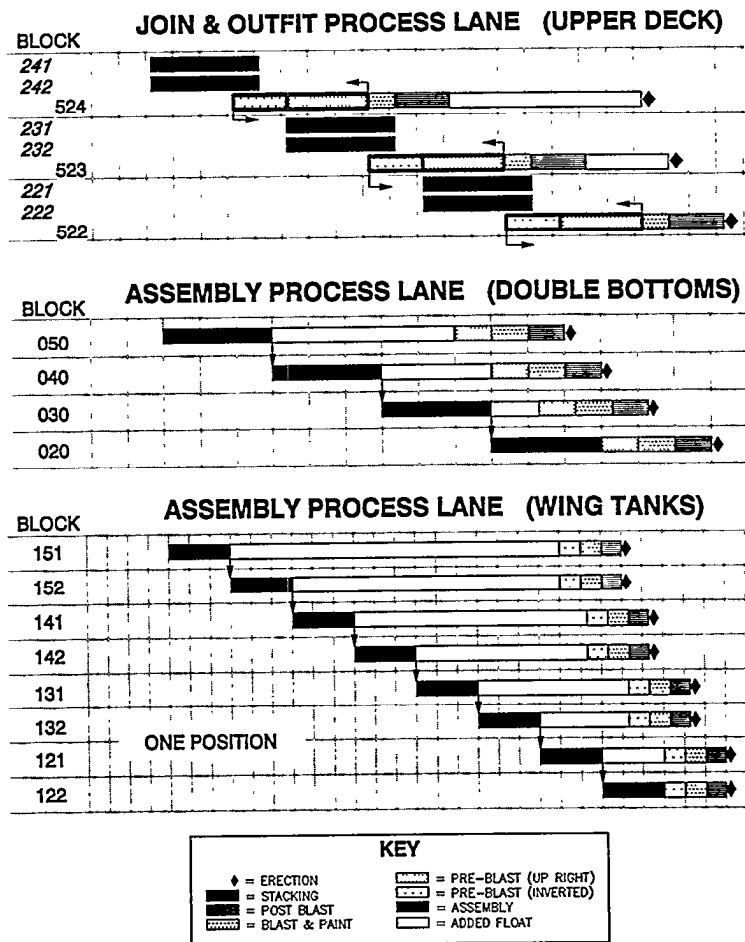


Figure 13 : Process lane strategies type for M/V WELL PLANNED.

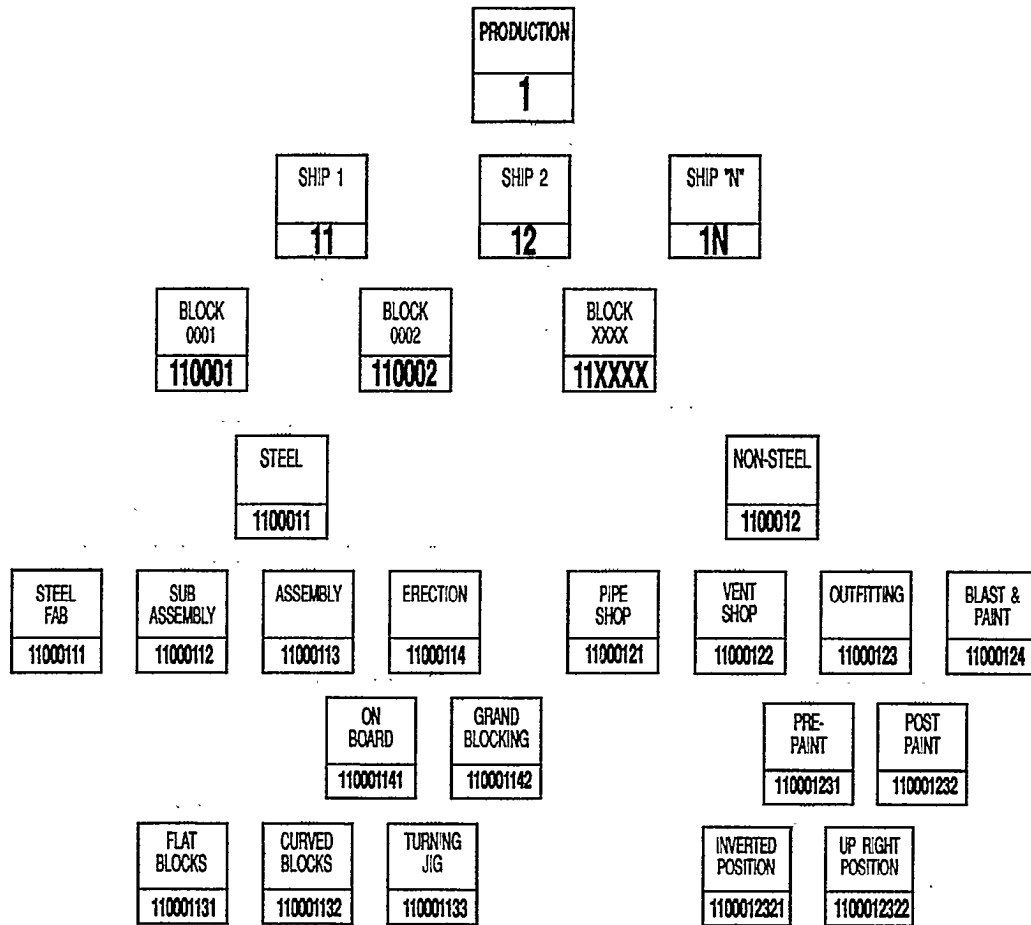


Figure 14 : Typical shipyard WBS.

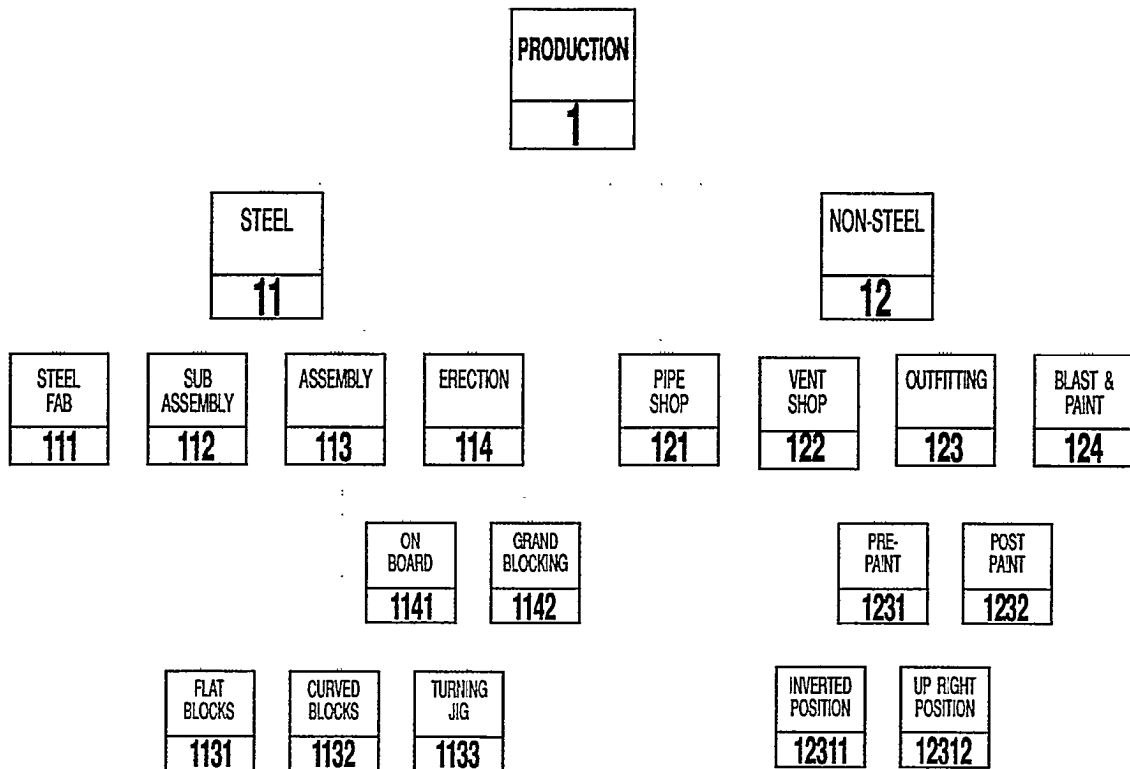


Figure 15 : Typical shipyard OBS

Information from the documents shown is used to create the M/V Well Planned's Ship Build Master Data File. This file is processed by the Model Builder Program to create a Standard Set Back Model for the ship. This model consists of the activities, resources, and relationships required to assemble and outfit the blocks in preparation for erection. The erection activity for each block is fixed to a particular date as defined by the strategy sheets. Since the final event in each chain of activities is locked, the entire network of activities can be back-scheduled to show the late start and complete dates for each activity in the network.

The standard setback model of the M/V Well Planned showed the required start of construction date for the vessel to be 22 weeks before keel. This is not acceptable. To alleviate this situation the build strategies must be altered. In the case of the M/V Well Planned start of construction is driven by the wing tank block assembly process lane. To solve this problem the strategy was altered by using a second build position for this process lane. The revised process lane strategy sheet to reflect this change is shown in figure 16. The model is altered to reflect this new strategy by updating the relationships between the wing tank block assembly activities. The model is then reprocessed. The start of construction date with this new strategy becomes 10 weeks before keel. The build strategy is now acceptable.

ASSEMBLY PROCESS LANE (WING TANKS)

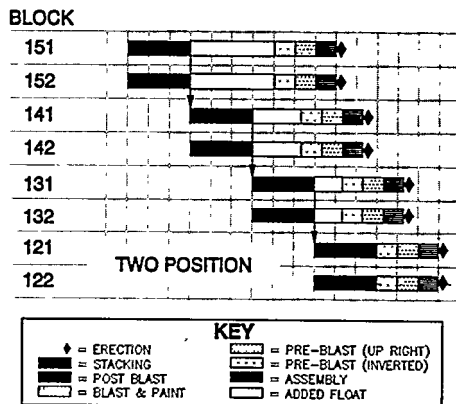


Figure 16 : Revised process lane strategy sheet.

The initial model is back-scheduled to late dates, therefore any leveling done is accomplished by moving activities earlier. Resource leveling strategies must reflect the constraints imposed by a particular yard's capabilities. If a yard has only a limited area to assemble the blocks, schedules may be leveled on blocks going through this particular area. If there is a required trade for which the yard has limited manning, schedules may be leveled based upon the trade's availability. Schedules may be leveled on any resource or combination of resources included within the model. Since the Integrated Production Planning System operates by back scheduling to late dates, the generalized resource leveling strategy is to first level resources in the area that immediately precedes the erection activity and then work back to earlier activities.

The strategy used for resource leveling of the M/V Well Planned is to first level the outfit area manning. Since resources are interchangeable between pre-blast inverted, pre-blast upright, and post blast outfitting activities, these activities are grouped by their common OBS code and leveled together. Once the outfitting area is leveled the assembly area is investigated. The assembly area in this example is leveled based upon the number of blocks with work in progress in both the flat and curved block build areas. By leveling first the outfitting area manning and then the assembly area work in process, a feasible Master Production Schedule is created. This schedule reflects the build strategies for the vessel as well as taking into account the manning and facility availability.

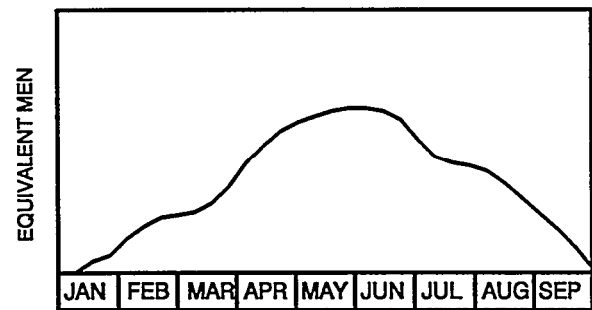


Figure 17: Outfit area manning requirements, iteration 1 - by standard setbacks.

Figure 17 shows the output of the long range manning requirement generation program for the outfit area. An analysis of the blocks outfitting during the peak months of April, May, and June show that the majority of the manning requirements during this period of time are driven by the outfitting of the house blocks and house grand blocks. In order to level manning in this area the outfitting of the lower house (grand block 531) will be scheduled prior to the outfitting of the upper house (grand block 533). To change the model to reflect this strategy a single relationship is added. The new relationship forces the outfitting of block 531 to complete before the outfitting of block 533 can start. Since the activities are linked, the system will reschedule the assembly, outfitting, and stacking activities of all blocks which comprise grand block 531. The results of this reschedule (iteration 2) are shown in figure 18.

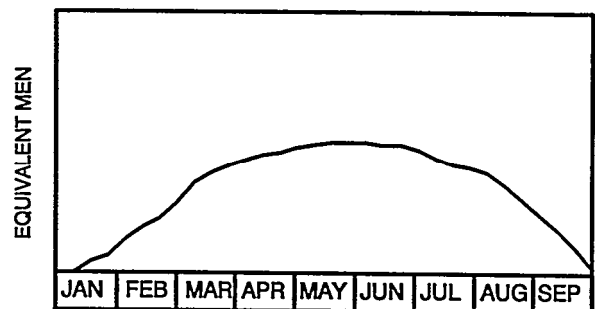


Figure 18: Outfit area manning requirements, iteration 2 - grand block 531 forced early.

The manning curve for the outfitting area is now acceptable. Next, an analysis is made of the facility utilization within the assembly area. Two independent resources must be investigated within the assembly area. Both the flat block build platen and the shaped block build platen have limited space. The MPS must be adjusted so as to level both of these resources. Since the resources are independent, they may be leveled simultaneously.

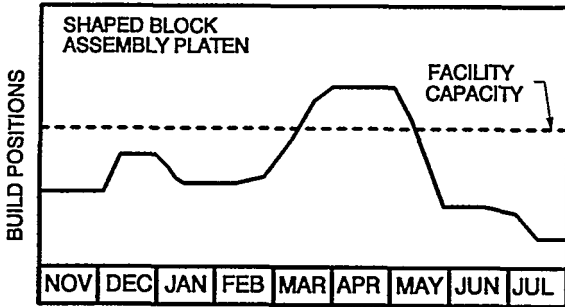


Figure 19: Shaped platen facility utilization based upon iteration 2 of the model.

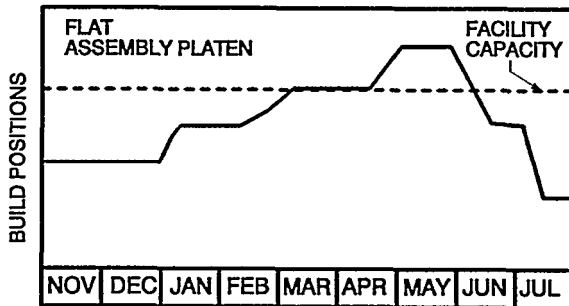


Figure 20: Flat platen facility utilization based upon iteration 2 of the model.

Figures 19 and 20 show the outputs of the capacity requirement generation program. Note that the system is back-scheduling to late dates and the assembly activity precedes the outfitting activities. Therefore, when assembly activities are forced earlier, float is introduced between the assembly and outfit operations. This has no impact on the outfitting area manning requirements. The resource leveling strategy for the M/V Well Planned makes no attempt to level the assembly area manning. However, there is a high correlation between assembly build positions in use and assembly area manning requirements. If assembly build position usage is level, assembly area manning requirements are also fairly level. To level the shaped block assembly platen, some of the blocks scheduled to assemble in April are rescheduled to assemble earlier to fill in the valley in the February-March time period. When leveling the flat block assembly platen it is not desirable to take the excessive work in May and reschedule it for February. This would break the logical build sequence for the ship. Instead, the schedule should be modified to push earlier the building of a few blocks in March, April, and May. This will eliminate the excessive capacity requirements while maintaining a proper build sequence. The results of this rescheduling (iteration 3) are shown in figure 21 and 22.

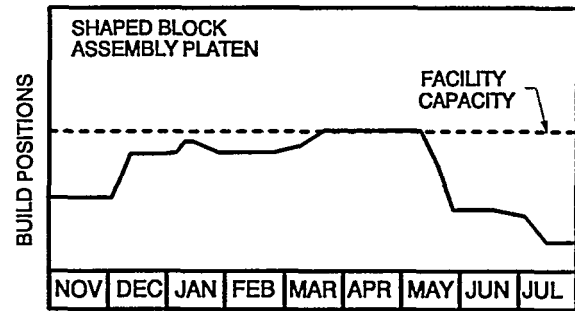


Figure 21: Shaped platen facility utilization based upon iteration 3 of the model.

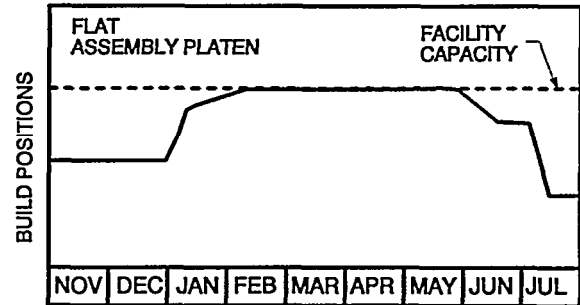


Figure 22: Flat platen facility utilization based upon iteration 3 of the model.

The facility utilization within the assembly area is now acceptable. This model is named the baseline production model and processed by the Master Schedule Generation Program to create a Master Production Schedule. The MPS is approved by production engineering, materials and support groups and the schedule is issued. An upload file is created to support the schedule tracking system.

A copy of the baseline production schedule is renamed the production update model. This model is updated based upon weekly meeting and progress data. These weekly meetings are attended by members of the assembly, outfitting, and erection groups. These meetings serve to update the short term schedule documents based upon actual and projected progress. The steps in updating the short term production schedule are illustrated.

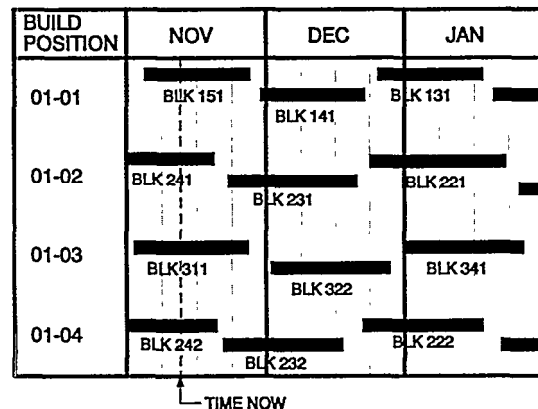


Figure 23: flat platen assembly laydown chart.

Figure 23 shows the current production schedule for the flat platen assembly area. At the production update meeting, the assembly area representative will report on actual and projected progress. The assembly area laydown chart is marked up by the assembly area representative as shown in figure 24. Based on the assembly area inputs, changes will be made to the production schedule. These changes are shown in table 2. The production update model is modified to reflect the actions taken in the meeting. The model is reprocessed. Updated production schedules are issued to appropriate groups.

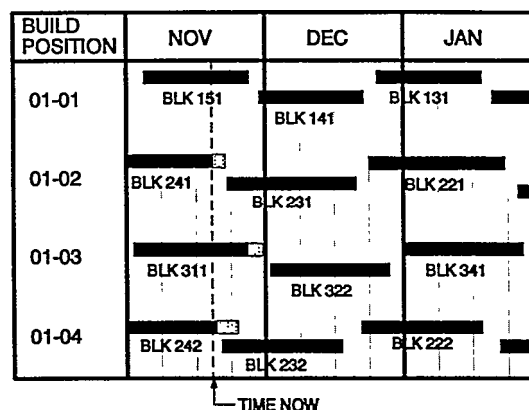


Figure 24: Flat platen assembly laydown chart as modified by the assembly area rep. at the production update meeting.

CONFLICT	ADJUSTMENT
<p>BLOCK 242 IN BUILD POSITION I-4 WILL OVERLAP WITH LAYDOWN OF BLOCK 232.</p> <p>THE EXTENDED DURATION OF BLOCK 311 IN BUILD POSITION 1-3 DOES NOT CAUSE A CONFLICT IN THE ASSEMBLY AREA. HOWEVER, THIS 3 DAY DELAY WILL CUT INTO THE SCHEDULED OUTFITTING DURATION.</p> <p>THE EXTENDED DURATION OF BLOCK 241 IN BUILD POSITION 1-2 HAS NO IMPACT ON OTHER BLOCKS IN THE ASSEMBLY AREA. THERE IS FLOAT BETWEEN THIS ACTIVITY AND THE OUTFITTING ACTIVITIES OF THIS BLOCK</p>	<p>ASSEMBLY AGREES TO CRASH THE DURATION OF BLOCK 232 IN ORDER TO RECOVER TO THE SCHEDULE.</p> <p>OUTFITTING, MADE AWARE OF THE DELAY AND ITS IMPACT AHEAD OF TIME, AGREES TO WORK THIS BLOCK MORE AGGRESSIVELY TO MAKE UP FOR THE DECREASED DURATION.</p> <p>LATER ACTIVITIES ARE NOT AFFECTED, THEREFORE, THIS DELAY HAS NO IMPACT.</p>

Table 2: Adjustments made to the production schedule.

CONCLUSION

An effective MPS must reflect a build strategy, material and engineering availability, and facility and manpower availability. A PC-based system can be established to assist in creating and updating the MPS. Such a system is currently being developed under NSRP task N8-91-6. When the full report is made available, it will be more detailed in its description of the production planning system. The final NSRP report will give recommendations on how the Integrated Production Planning System can be improved and expanded. The final report will also give guidelines and recommendations as to how to adopt this system for use in other shipyards.

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The Pan Pacific Hotel, San Diego, California, September 3-6, 1991

Photogrammetry - Automating the Collection of Shipcheck Data

VIIB-1

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ABSTRACT

The installation of new or modified systems on board U.S. Naval combatants during overhauls requires advance planning shipchecks. One primary purpose of a shipcheck is to document existing shipboard conditions in order to develop engineering drawings for the installation of these new systems. Gathering and documenting existing shipboard conditions has always been a very labor intensive effort. Also, accuracy of measurements is restricted by congested spaces, dimensions of extensive length, and intricate configurations of systems. Furthermore, the accuracy of the shipcheck information relates directly to the quality of the production installation. Accurate well-planned ship check information will reduce production interferences, production costs and schedule variance. One objective of a planning department is to reduce manday expenditures required to accomplish a ship check while increasing the accuracy of the data gathered. Automating this ship check using photogrammetry, specifically stereo photogrammetry, can provide a means to achieve these objectives. This paper will explore the use of stereo photogrammetry to gather ship check data for shipboard distributive systems such as piping, ventilation, cable ways, compartment arrangements and structural components.

BACKGROUND

What follows is a description of how a typical advance planning ship check is accomplished. First, the task is identified. This typically may require the removal or modification of existing systems and the installation of new mechanical or electrical systems. Structurally it may require the removal, penetration or modification of existing structures or instal-

lation of new structures to accommodate these new or modified mechanical or electrical systems.

The decisions to modify existing systems or install new systems are made by shipyard engineers and technicians responsible for each system. Existing conditions are examined and evaluated and decisions formulated on how the task will be accomplished. Each technical code or discipline is then required to gather the necessary data in order to accomplish their portion of the entire task.

Generally, personnel from all engineering disciplines (structural, mechanical, and electrical) will ship check the same compartments to obtain needed information to complete their individual drawings. This leads to duplication of effort as well as added opportunity for error in measurements with several people locating points of interest from different vantage points.

Following is an example of where error in measurements and duplication of effort can enter into the process. A mechanical engineer may locate a new piece of equipment off a bulkhead, deck, or structural stiffener. An electrical engineer may have to locate power boxes in this compartment to provide power to this new piece of equipment, while the structural engineer is required to provide a foundation. All three will need to sketch the existing structure. With the breakdown of several systems over many technical groups it becomes readily apparent that many people will be duplicating measurement efforts even in this simple example. This process also allows for unavoidable measurement errors. As an example (figure 1), dimensions of an existing transverse beam can be taken from a

forward bulkhead by one person and an aft bulkhead by another. Since both bulkheads are located on a frame, both dimensions taken should give the same location of the beam. However, these bulkheads, for one reason or another, are typically not exactly on frame. Errors during installation, by excessive loading, or deformation from damage are but a few reasons for these misalignments.

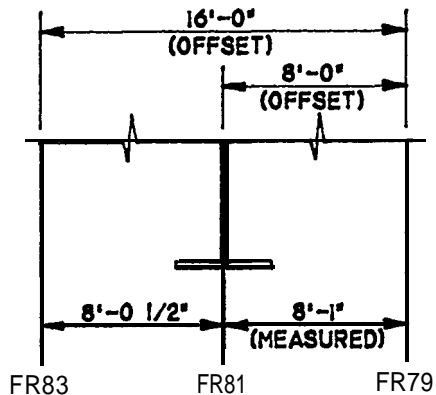


FIGURE 1.

DISCUSSION

Ship checking with photogrammetry can be accomplished with either or both of the two methods used in photogrammetry, convergent or stereo. Convergent is generally more accurate, but requires all points of interest to be targeted prior to photography. Stereo is generally more versatile in ship checking applications since data points are gathered in the office from stereo pairs (overlapping photos) which produce a "3D" picture for data extraction. Other situations where stereo is the method of choice over convergent include the inability to physically place targets, large degree of congestion when determining camera vantage points, and excessive number of data points required to define an object.

Photogrammetry can be used effectively in ship checking to resolve some of the short comings of conventional ship checking. First, data points that are captured can only be at one coordinate point, whether the coordinate system is local or in the ship's coordinate system. Not only are measurement errors eliminated, but the actual dimensions themselves are more accurate. Secondly, photogrammetric

data points that are input in a CAD unit for reconstruction allow the "ship check" to be performed in the office. "Ship checkers" are not affected by environmental factors such as hot or cold weather, movement of ship, rotating equipment or environmental hazards such as radiation. Also, unavailability of key personnel being able to travel to remote sites for long periods of time can be overcome. The inexperience of a ship checker can be virtually eliminated as a contributing factor to ineffective ship checking. Finally, with the use of stereo photogrammetry any change in guidance occurring after completion of shipcheck can be overcome. For example, a change in equipment vendor could result in a larger unit being installed, thus requiring additional systems to be relocated or modified. Stereo pair photographs can be reused to extract additional information that may be required at a later date. With conventional shipchecking methods, a revisit to the ship is almost always required.

PLANNING

An example of shipchecking with photogrammetry is a recent project on the USS CONSTELLATION (CV64). The area selected for the photogrammetric survey was Pump Room #5 (7-195-0-E) which contains fuel oil and fire pumps, air conditioning plants and the associated distributive piping systems. This compartment also contained a false floor or grating which limited accessibility to the areas being surveyed (figure 2).

As built installation drawings and ship alteration drawings for the pump room were reviewed. Various piping systems, Ventilation systems, equipment and structures were selected for the photogrammetric survey. The criteria for selecting systems to shipcheck consisted of areas that were congested with limited accessibility, systems with complicated arrangements that would be hard to shipcheck manually, and systems from varying disciplines to determine if any pose unique difficulties or peculiarities. With the use of stereo photogrammetry it was not necessary to decide on specific data points during the site preparation and photo phase, rather it was only necessary to decide on which systems or groups of systems were required to be picked up in order to plan the camera stations (points from where photos would be taken).

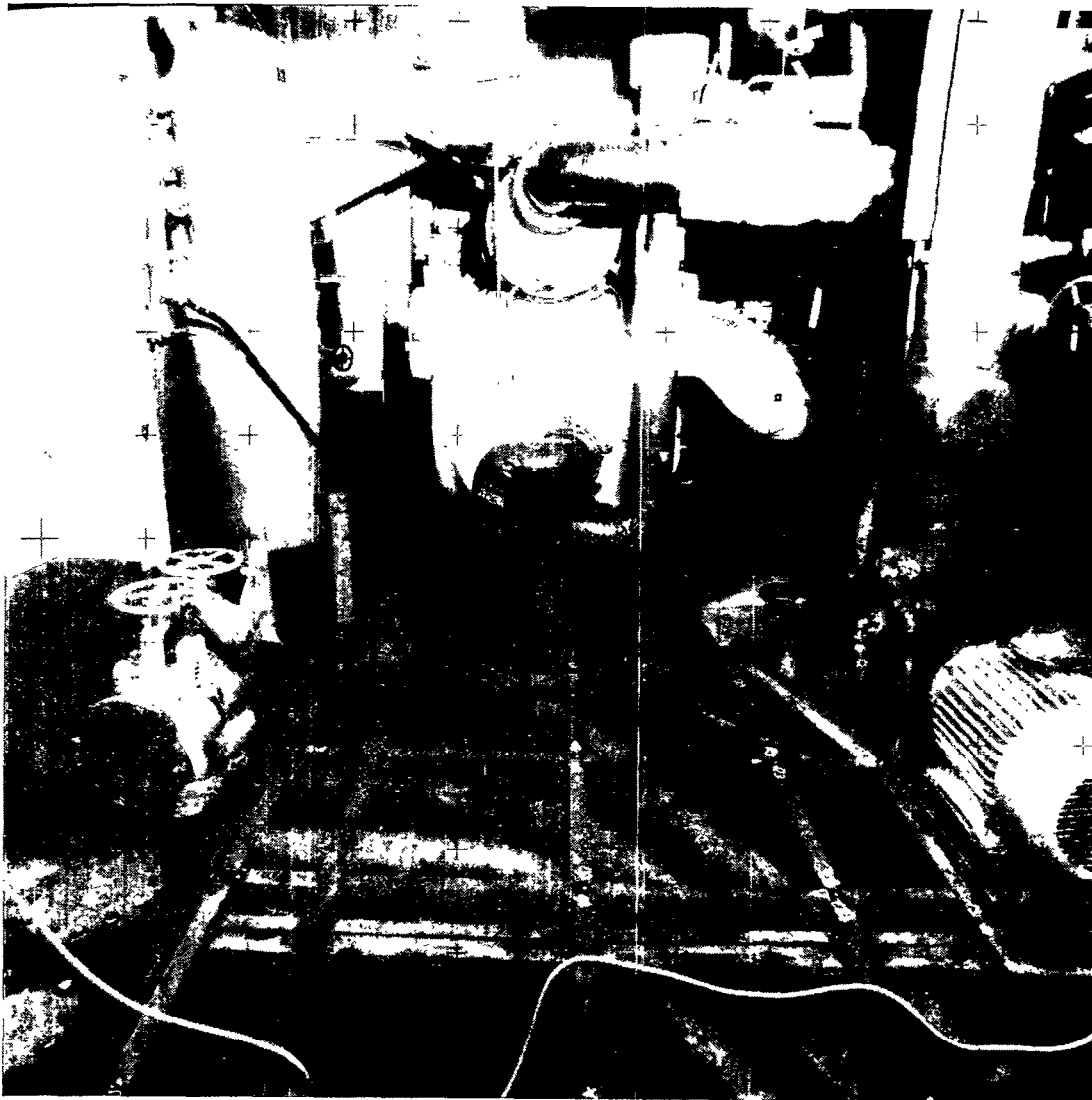


FIGURE 2. PUMP ROOM #5

Convergent photogrammetry was used to set up a coordinate system in relationship to the bulkheads that made up the boundaries of the compartments and to tie the photos together into a network. In this case the bounding angles that remained after deck plates were removed provided locations for the convergent targets to be placed.

As with any photogrammetric project the planning included determination of camera and film medium (controlled for the most part by accuracy levels required), amount of lighting required across the full spectrum of the photograph to allow for sufficient exposure to read the negatives, proper highlighting to provide enough contrast to identify data points and location, and frequency of photos to ensure sufficient coverage.

A semi-metric Rolleiflex 6006 camera employing 70mm Kodak Plus-X Ester-base film was chosen due to its ability to obtain data within our 1/8" accuracy requirements. Also, film as opposed to glass plates allows you to progress at a much faster rate.

With the preplanning completed? some of which was accomplished during the shipcheck, the site preparation could begin. This consisted of placing and numbering targets used in the convergent portion of this project, laying out camera stations and outlining foundation edges and lightening holes with paint to provide contrast. Photos were then taken and reviewed to ensure that both quality of photos and areas of interest were captured (figure 3). That essentially completed the photogrammetric portion of the shipcheck.

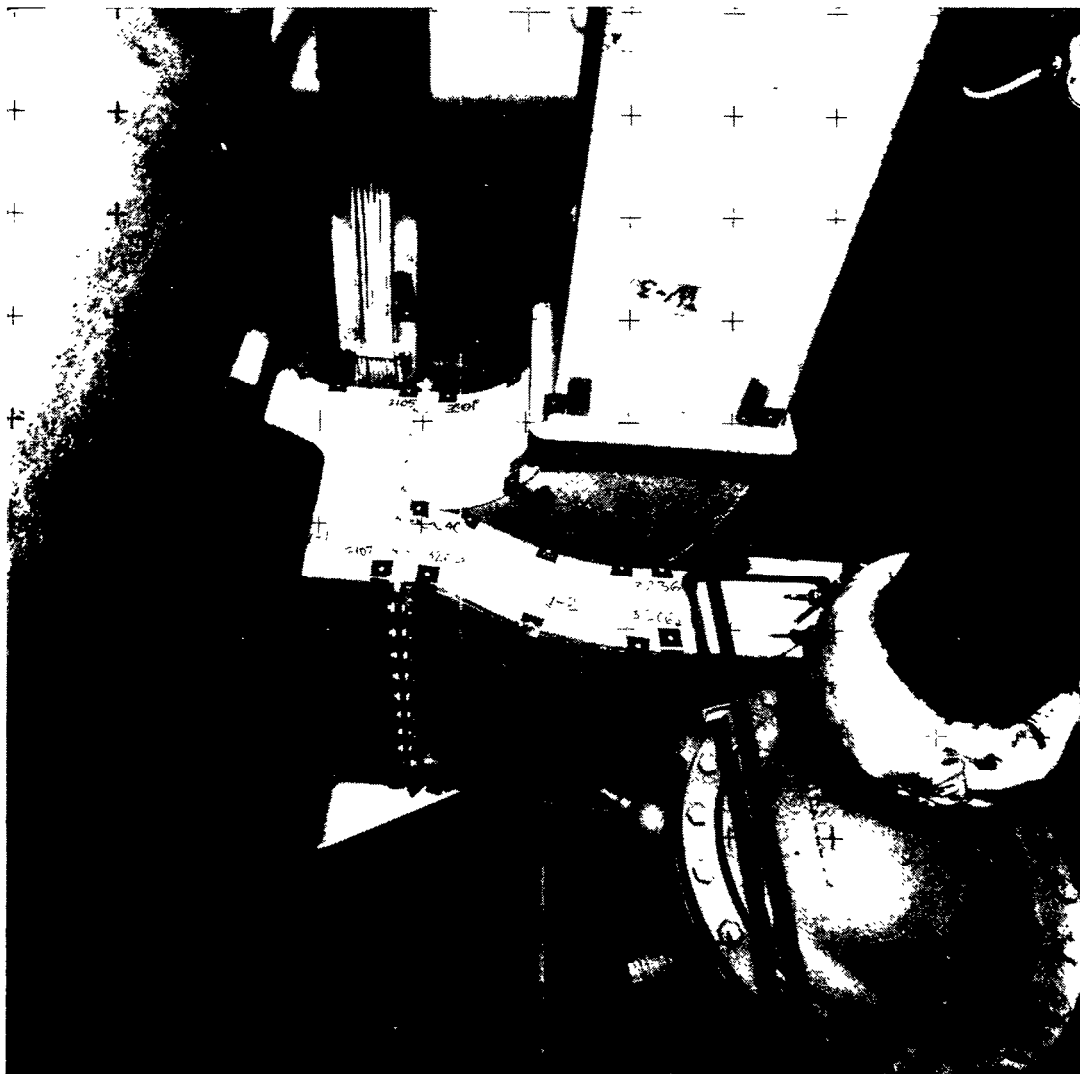


FIGURE 3. PUMP ROOM #5, OVERHEAD VENTILATION

In the office stereo photo pairs were placed in the analytical compiler and objects of interest such as piping systems were measured. The process of measuring photos and providing X,Y,Z coordinates is commonly referred to as data reduction. The analytical compiler provides X,Y,Z dimensions. Three dimensional measurements of photographs requires an experienced photogrammetric technician to correctly measure the points.

One of the goals of this project was to take the coordinates generated from the photogrammetric survey and reconstruct CAD drawings. A computer tape of the X,Y,Z coordinates was loaded into a Computer Vision CAD system. This raw data was plotted as points in space (figure 4 and 5). The CAD operator used these points to develop detailed system drawings.

The photogrammetric pictures were also necessary, along with the plotted points for the CAD operator to develop these drawings. The pictures allowed the CAD operator to relate the data points to shipboard conditions. An area of CAD reconstruction that should be emphasized is the importance of the photogrammetric technician who is responsible for digitizing the X,Y,Z coordinates of the stereo pairs. If the photogrammetric technician is aware of the type of dimensions required by the CAD operator the data supplied may be sufficient to develop the CAD drawings. It appears however, that the CAD operator and the photogrammetric technician must have a close working relationship in order to process additional information as required.

The CAD operator must also provide the intelligence to the data points.

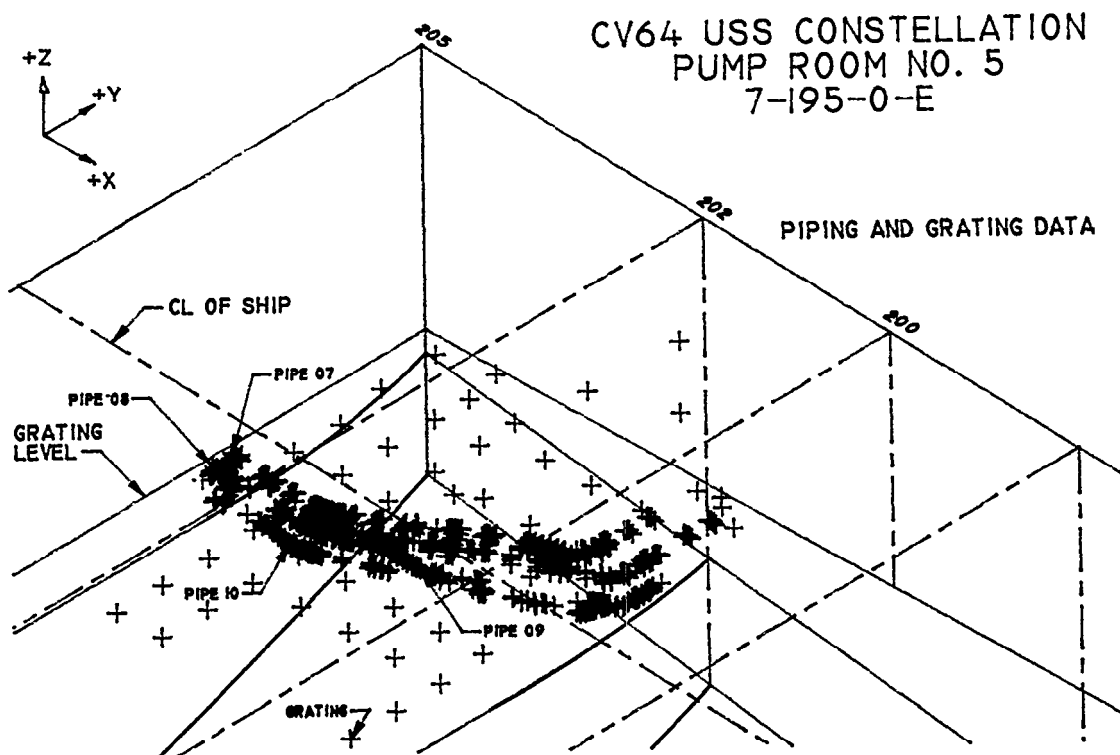


FIGURE 4. PLOTTED POINTS REPRESENT XYZ COORDINATES OF PHOTOGRAMMETRIC TARGETS IN 3-D SPACE

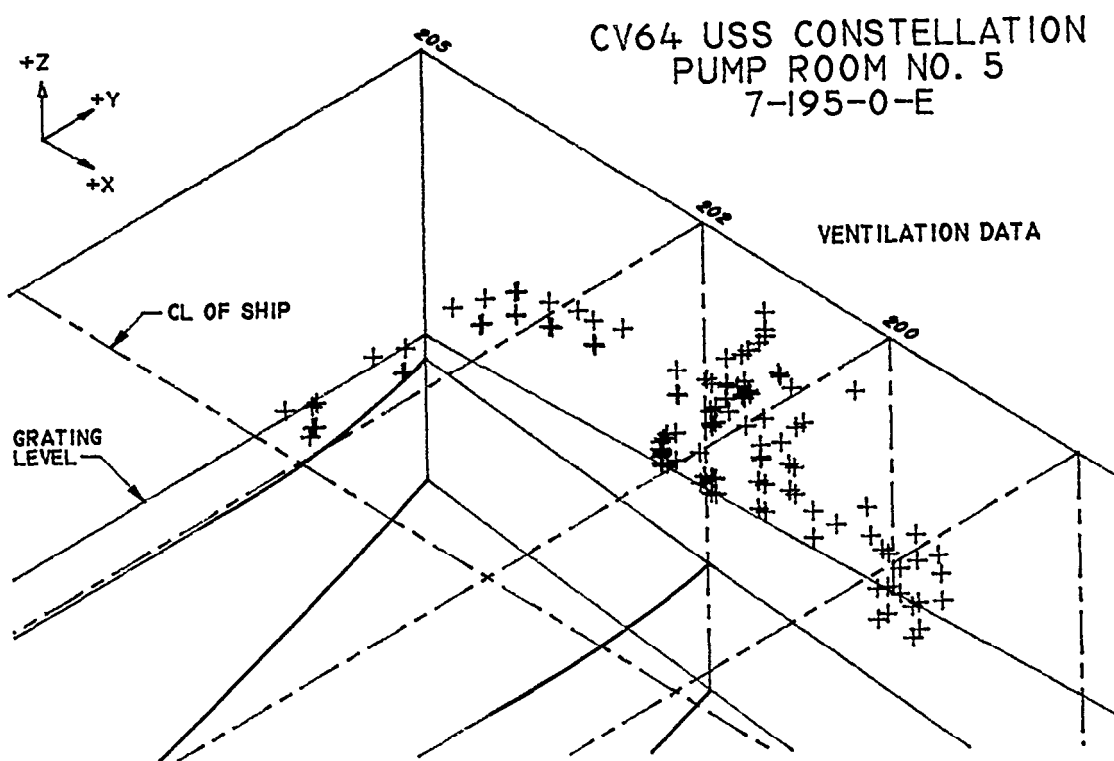


FIGURE 5. PLOTTED POINTS REPRESENT XYZ COORDINATES OF PHOTOGRAMMETRIC TARGETS IN 3-D SPACE

He or she must attach the characteristics/parameters to systems being constructed such as material, wall thickness, size etc. The point to be emphasized is that photogrammetry is not a turn key operation to drawing development. The reconstruction of photogrammetric information into CAD drawings requires skilled CAD operators and time. Photogrammetry provides accurate locations that document existing conditions, the CAD operator creates the engineering drawing (figure 6-8).

RESULTS

The aspects of this project that were critiqued are the ability of the equipment to capture the data, the accuracy of the data gathered and cost comparisons of a conventional shipcheck versus a photogrammetric shipcheck.

The areas chosen to be surveyed **were** selected because of the difficulty they would have presented if shipchecked manually. As

mentioned earlier, the systems surveyed contained complex geometries or were located in hard to access areas. None of these situations proved difficult for gathering photogrammetric data.

It should be noted that this area was previously shipchecked manually to support an upcoming overhaul. This allowed us to compare results of the survey to a manual shipcheck. The table below compares manually measured shipcheck information versus photogrammetric data for two piping runs. The measurements shown are at the bulkhead penetrations (Table I).

An acceptable level of accuracy for a manual shipcheck is 12.7 mm (.5"). This is an arbitrary number chosen mainly from past shipcheck experience. A comparison of the differences between photogrammetric data and manual shipcheck data, given the allowable accuracy of the manual measurement, demonstrates favorable results.

One of the biggest problems of a manual shipcheck is missing

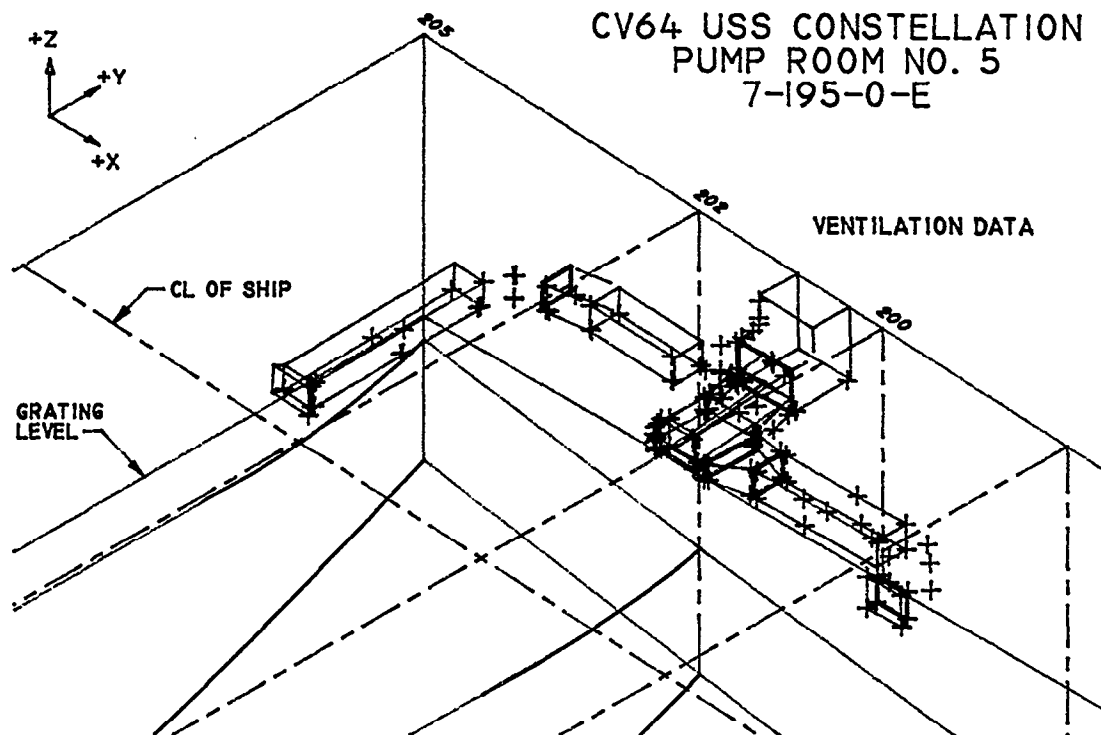


FIGURE 6. LINES FROM POINT TO POINT TO RECONSTRUCT VENT IN 3-D MODEL

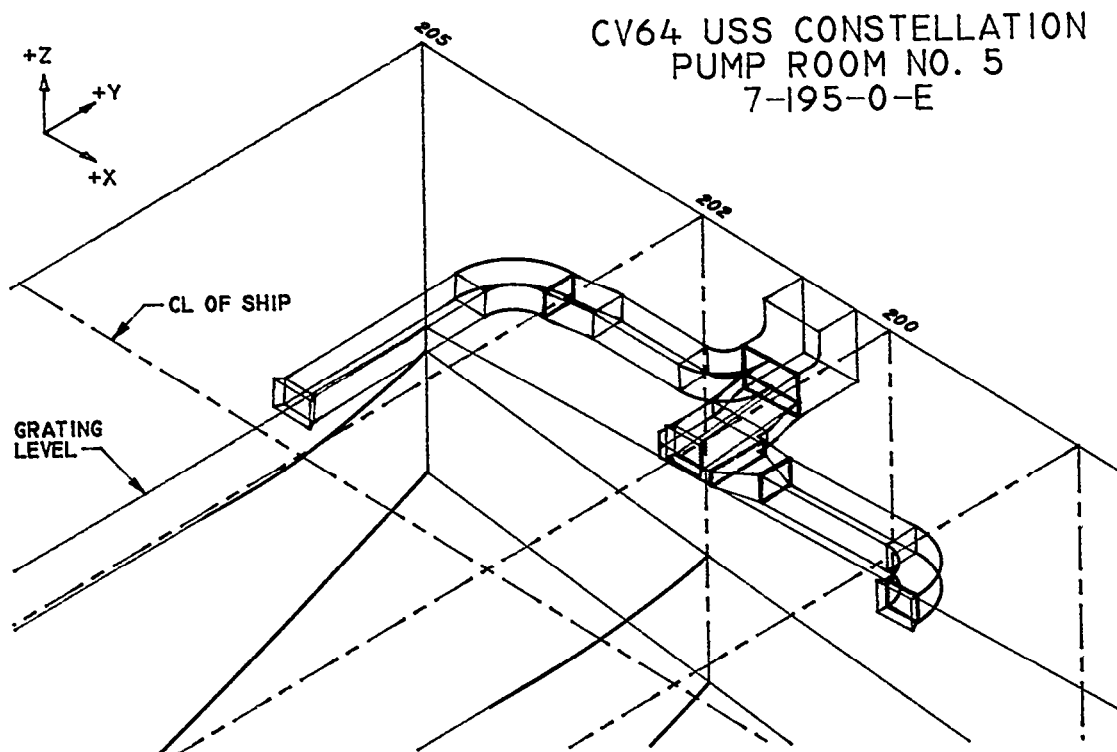


FIGURE 7. 3-D CADD MODEL RECONSTRUCTION OF VENT FROM PHOTOGRAMMETRIC DATA

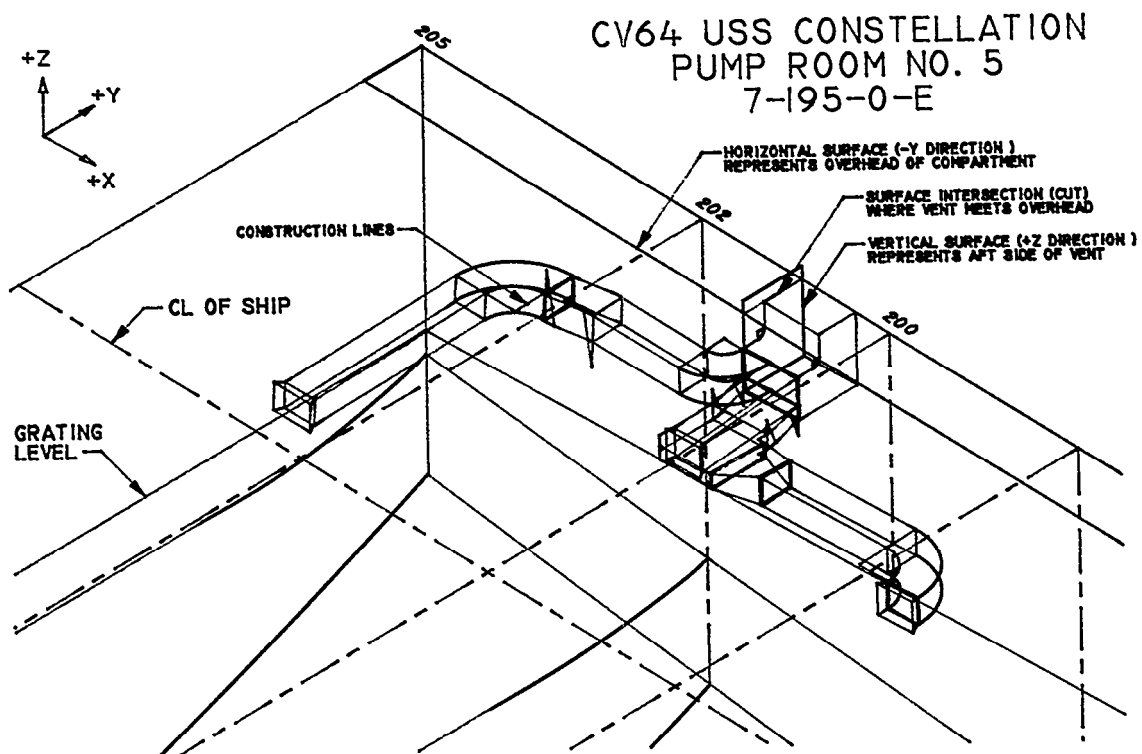


FIGURE 8. SURFACES AND CONSTRUCTION LINES USED TO RECONSTRUCT VENT IN 3-D MODEL

TABLE 1, DATA COMPARISONS

PIPE	PHOTOGRAMMETRIC	MANUAL	DELTA	MAN s/c ACCURACY
	DIST. FROM BHD 205			
P-8	3879.85MM (152.75IN)	3881.12 (152.8)	1.27 (.05)	+12.7 (.5)
P-10	3949.85MM (155.5IN)	3961.13 (155.95)	11.43 (.45)	
	DIST. FROM LONG. BHD			
p-8	2856.18MM (112.45IN)	2857.5 (112.5)	1.32 (.052)	
P-10	2831.6MM (111.48IN)	2838.45 (111.75)	6.86 (.27)	

information or oversights by shipcheck personnel. Besides accuracy, the other advantages of a photogrammetric survey is the ability to retrieve additional data at a later date. For example, with the use of photogrammetric shipcheck data, a location of a fitting that was omitted from the survey data can be requested by the CAD operator at any time. This one benefit alone is invaluable in increasing the quality of engineering prints.

The cost comparisons of manual shipchecks and photogrammetric shipchecks are projected to be equal. Although the number of personnel needed to actually gather the information on site can be reduced, this is offset by the additional cost of reducing the data from the stereo pairs.

CONCLUSIONS

First and foremost, this project has proven that photogrammetry can gather shipcheck data for distributive shipboard systems. The data is also accurate compared to conventional methods of shipchecking. An intangible benefit that can not be overlooked is the ability to retrieve additional data at a later date. This project also demonstrated the flexibility of the equipment to shipcheck in congested areas and, as mentioned above, the cost of shipchecking using photogrammetry is comparable to conventional shipchecks. This is the first step in automating the shipcheck process.

Future efforts will be directed at refining procedures, such as expanding the survey to include multiple compartments, and investigating the techniques required

to "tie in" all the data into one package. Another area being investigated is the proper applications of this technology. Are there certain shipcheck projects that lend themselves to stereo photogrammetry more than others? The goal of future research will be to refine the procedures to the extent that photogrammetry can become a routine shipcheck tool to be applied to high risk and complex shipchecks.

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Productive Method and System to Control Dimensional Uncertainties at Final Assembling Stages in Ship Production

VIIIB-2

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ABSTRACT

Strict dimensional control of interim products through the different assembly stages is vitally important profitable ship production (1). Studies made in Finland show that a 30% reduction in labour costs is possible in hull construction (2). This reduction can be gained by eliminating unnecessary fitting and reworking using tight accuracy control methods.

Although accuracy control of the prefabrication stages is important because it forms the basis for the hull production, the dimensional control of the block assembling stages is essential if major improvements in productivity are to be achieved.

Fig.1 explains the situation. The figures for the diagram were collected from measurement experiments carried out at major Western shipyards during the years 1989-91. Usually the accuracy level of the production is reasonable at the first stages, but the inaccuracies increase rapidly and most nonlinearly as a function of the complexity of the interim products. This means that the assembling methods have a strong influence on the dimensional uncertainties of the interim products (blocks) at the final assembly stages. At the same time the labour costs in these final stages are very high. Thus notable productivity improvements can be gained by implementing progressive assembling methods and dimensional control systems at these final assembly stages.

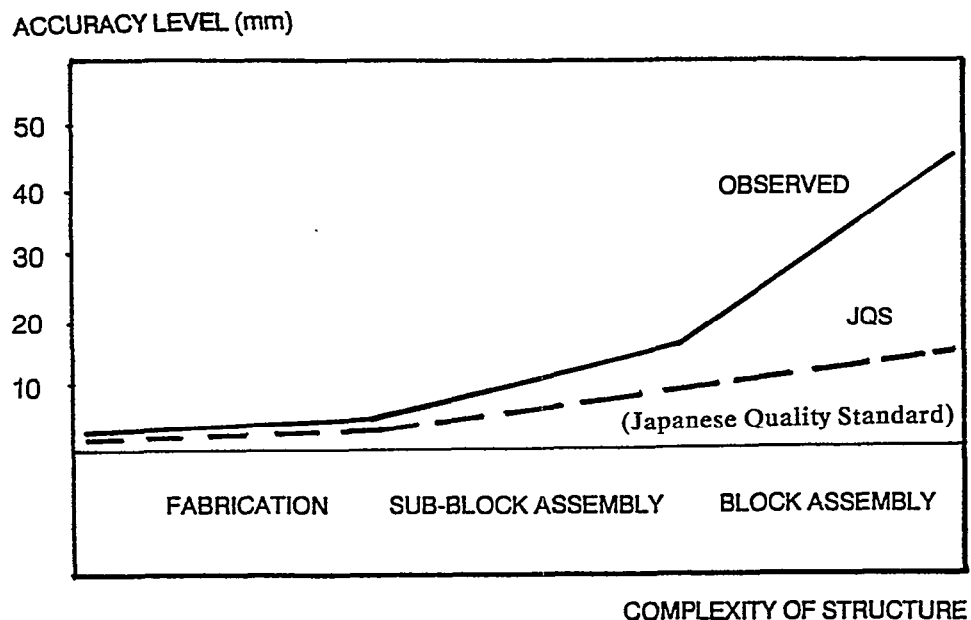


FIGURE 1

One key problem is how to effectively organize the dimensional control of the production of large shipblocks. A modern approach is to use three dimensional (3D) coordinate measurement systems (3). Although these new systems provide excellent means of taking measurements, there remains a problem of applying the systems in a way that allows a straightforward interpretation of the results. The resulting interpretation should be applicable to different purposes. One objective is to meet the need of fast real time measurements on site; another is the monitoring of dimensional accuracies of different assembly stages as well as the use of the collected measurement data to improve the design and production methods.

This paper presents a method for dimensional control of block assemblies. The dimensional control is thereby separated from the positional control of the block. The method is a 3D-coordinate based approach relative to a positional reference system. Also described is a real dimensional control case and an evaluation of different measurement technologies in performing the proposed task. The evaluation is made comparable to a system study performed at the National Steel and Shipbuilding Co. (NASSCO) Shipyard, San Diego, USA during

METHOD

Problem Statement

A major problem related to profitable ship production is manufacturing of shipblocks of optimal accuracy. A key factor therefore, at major yards with proper control of the part production process, is to minimize rework at the hull erection stage.

The hull is normally assembled relative to a reference system. The reference system is based on a defined plane and on a line on this plane. The line is called center line (C.L.) and the plane is the bottom plane, on which the frame lines (F.L.) usually are named bottom lines (B.L.). This reference system is sketched in Fig.2. The basic plane and the line define a Cartesian coordinate system as shown in the figure. The axes of this coordinate system are: x-axis along the C.L., y-axis parallel to the frame lines, and z-axis defining the height from the bottom plane. We call this reference system a positional reference system. The same coordinate system is used when designing a ship. Because Computer Aided Design (CAD) systems are adapted to modern ship design in a continuously growing number, the use of coordinates play a vital role in controlling the manufacturing processes.

Two critical manufacturing problems can be distinguished at the final hull assembly stage. The first is a dimensional problem: the dimensions of the blocks will deviate from their nominal measures making the erection work tedious. The second is a positional problem: due to the dimensional uncertainties, the correct positions of the blocks are hard to define. Thus a block might have accurate dimensions, but be incorrectly positioned, or alternatively a block might be in correct position but have accurate dimensions. Often these problems are overlapping in the sense that a block might have both dimensional errors and be incorrectly positioned.

In practice the joining of blocks is done relative to the bottom plane and C.L. as mentioned above. However, when large dimensional deviations are encountered and the constrictions of the ship boundaries are considered, some compromise must be made regarding the positioning of the block.

Basic Definitions

When manufacturing blocks for the erection stage (these definitions can also be used for other assembly stages), two control tasks can be defined:

- 1) Dimensional control, meaning to control the dimensions and the shape of the block relative to the positional reference system defined (Fig.2) and
- 2) Positional control, meaning to control the position and the orientation of a block relative to the reference system defined.

Objectives

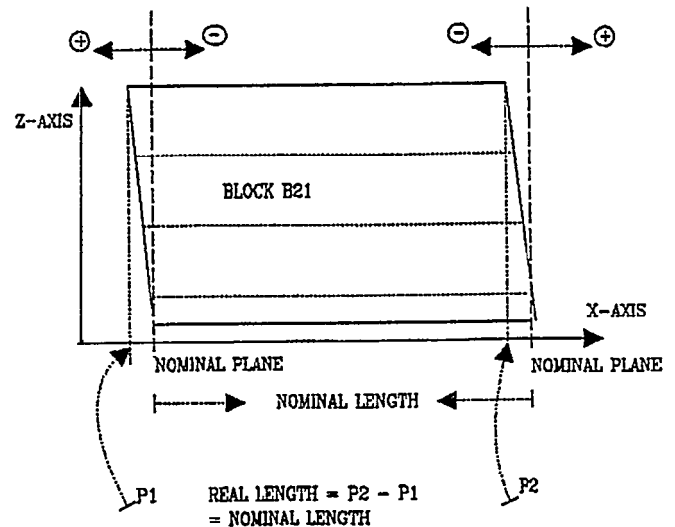
The method described herein focuses on producing ship blocks with optimal accuracy and minimizing rework in the erection stages. Thus three basic goals are considered:

- 1) The method should provide dimensional data relative to the block (not to the position of the block) making possible later analysis development manufacturing processes;
- 2) The erection and joining of the blocks should be done strictly to the positional reference (hull design coordinate) system;
- 3) All marked (vital) points on the block should be dimensional reference points of the block, or directly related to specific assembling methods or equipment of the prefabricating stages.

Description of the Method

The control method concentrates on the final assembly stages, but is also applied to earlier stages of production.

Dimensional Control. The dimensional reference system, shown in Fig.2, is used to express the exact position of a point on a block. When a position of a block is defined, then correspondingly the position of each point on that block is defined relative to the same reference system.



P1: POSITION ON X-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

P2: POSITION ON X-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

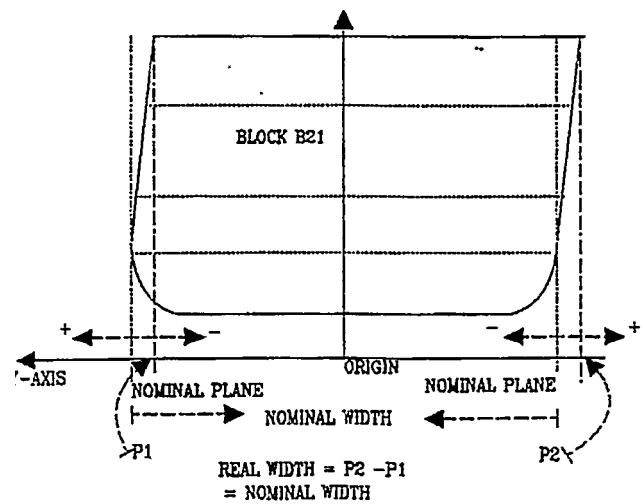
FIGURE 3

When dealing with the width of a ship the situation is similar as shown in Fig.4, where the same block is sketched on the y,z-plane. Once again the projection of point P1 shows a negative value, indicating shortage of material, and P2 a positive value? indicating excess material of the top deck, while the actual y-dimension of the deck is correct. Also in this case, when controlling the y-dimension, a "+" sign is defined to mean deviation outwards from the block and a "-" sign inward to the block.

FIGURE 2

When dealing with coordinate systems however, the above method might cause some confusion. For example, a block is sketched on the z,x-plane in Fig.3. If the shape of the block is distorted as shown in the figure, then the projections of points P1 and P2 (top deck) on the x-axis, are negative compared to their nominal values on the x-axis. This gives an impression of having shortage of material while the actual x-dimension (length) of the deck is correct.

This confusion can be circumvented by separating the x-dimension of the block from the position of the point defining the dimension. Thus in dimensional control the deviation from the nominal value is useful to define. Therefore a "+" sign is used when the deviation is outwards from the block and a "-" sign when the deviation is inward to the block, according to Fig.3.



P1: POSITION ON Y-AXIS (-SIGN COMPARED TO NOMINAL POSITION)

FIGURE 4

Correspondingly, the control of the z-dimension (the height) of the block is defined in the same way as the control of the x- and y-dimensions (length and width). Thus in dimensional control the signs of the block deviations from the nominal values are chosen as follows:

- "+" sign means that the deviation is outwards from the block
- "-" sign means that the deviation is inwards to the block

Positional control. In positional control the signs of the deviations are absolutely defined by the reference system and thus the position of each specific point in the construction space is uniquely defined by its 3D-coordinate value.

Establishing a Permanent Vital Point System

From a practical point of view, a reference point system is needed to implement the dimensional and the positional control method. This means that in each work piece there are defined points, called vital points which are used for taking control measurements. The points should be defined and marked so that they can be used for continuous dimensional and positional control. This means repetitive measurements are taken using the same points throughout the different assembly stages. These vital points should be marked permanently on each work piece at sub-assembly stages.

The vital points are defined and the nominal coordinate values of these points extracted from the design (CAD) system at the detailed design phase. Thus each steel structure has vital points preassigned at each assembly stage. It is essential to select the points in the way that the location of the point describes the dimensional performance of the particular assembly stage. Vital points can be grouped into three main categories:

- 1) Points which define the geometry of the block through all assembling and block transport stages (stiff points);
- 2) Points that assist in the later analysis of parts and sub-assembly accuracies and directly relate to production equipment and methods;
- 3) Points attached at specific assembly stages to assist the production team in block erection work and in dimensional measurement tasks.

The Importance of CollectionP Dimensional Data

The collecting of dimensional data in a way defined above is vitally important when monitoring and developing -manufacturing processes. Monitoring of accuracy levels of different assembly stages is based on the statistical analysis of dimensional variations of work pieces. To accomplish this, production standards for each type of assembly must be devised, sub-assemblies and blocks classified, and relevant production equipment and methods related to these classifications used. The monitoring is then done relative to well established accuracy limit values.

Of major importance in collecting the dimensional data is the development of assembly methods based on the trends in an accuracy data base. In the long run, this will lead to essential improvements in productivity (1).

Requirements for Control Systems

This dimensional control method is meant to be implemented using modern measurement and computer facilities. Several requirements for these kind of systems and their operation can be made:

- 1) The measurement technology should provide instant and efficient (on-line) coordinate measurement execution;
- 2) The control system should have a direct link to the yard's design system, enabling transfer of data between the control and the design systems;
- 3) The collection of the real measurement data should be organized so that future reference to the data bank is straightforward, making dimensional monitoring and analysis easy to perform.

The goal of such a system should be on-line "measuring to marks" by the production team which then uses the dimensional information for instant corrective decisions. The team can also perform post-analysis of the accuracy situation for fast feedback to the planning department for devising production improvements.

DIMENSIONAL CONTROL OF A BLOCK ENTERING ERECTION

Description of the Case

As pointed out, the dimensional control of blocks relative to the reference system (Fig:2) is vitally important in to eliminate unnecessary reworking when positioning the block correctly and joining two locks together, especially at the final assembly stages.

To illustrate the selection of vital points on a large structure, a drawing used for accuracy control purposes is shown in Fig.5 below. The structure is part of a twin hull 350 passenger luxury cruiser being built at the Rauma Yard, Finland.

Typical dimensions of blocks for larger vessels are height 10 (30), width 20 (60) and length 22 m (67 ft). The number of vital points on one end of block is ca 25 and the total for a symmetrical block is thus 50 points.

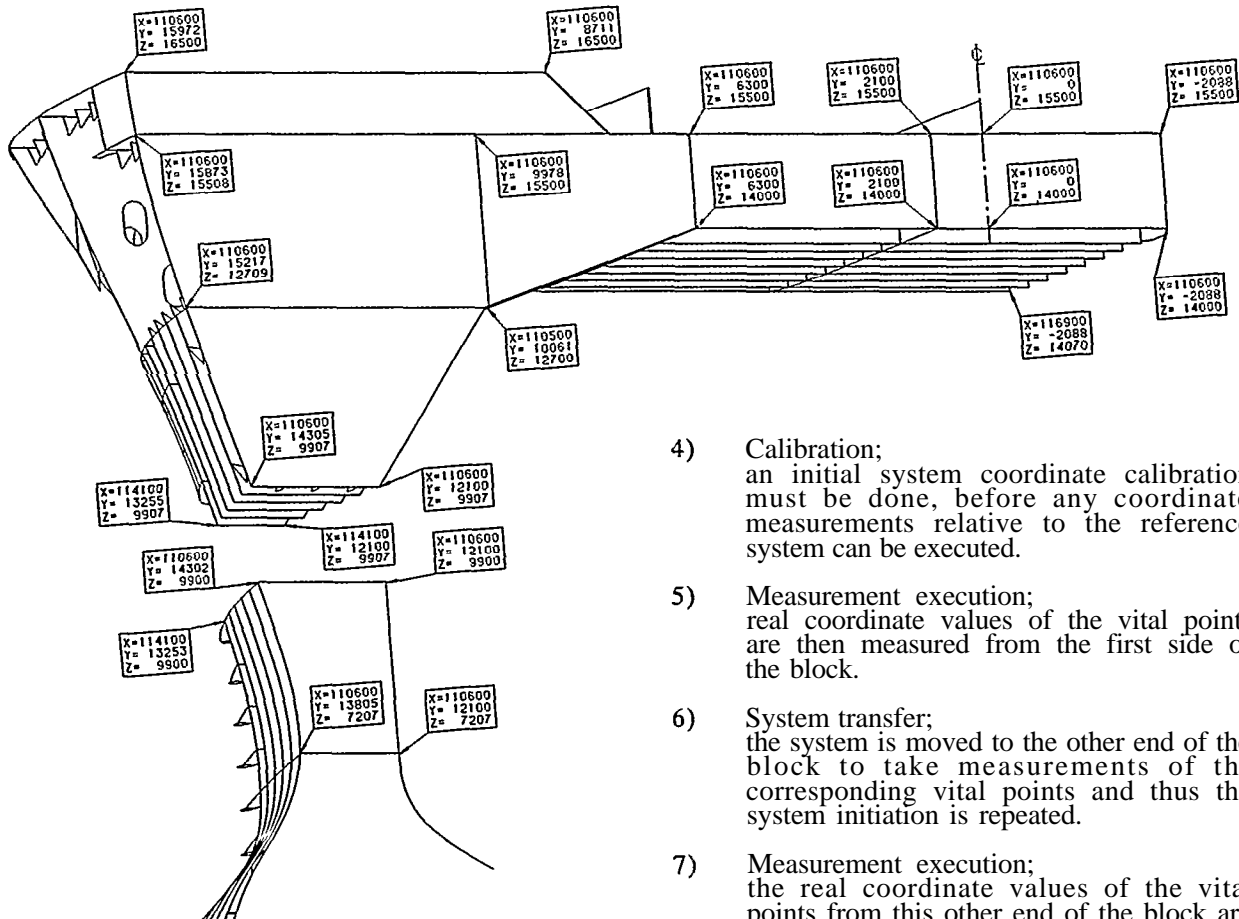


FIGURE 5

Measurement Tasks

The dimensional control of a block described above includes several tasks.

- 1) Planning the measurement; defining points to be measured, extracting the nominal coordinate values of the points, making a measurement sketch of the block, showing the locations of the measurement points, transferring the nominal and design data to the measurement and control system.
- 2) Setting up the measurement system; bringing the system on site and performing the system initiation.
- 3) Marking of the target (vital points); it is supposed that most of the vital points are permanently marked. Normally some additional points must be marked just before measurement execution.

- 4) Calibration; an initial system coordinate calibration must be done, before any coordinate measurements relative to the reference system can be executed.
- 5) Measurement execution; real coordinate values of the vital points are then measured from the first side of the block.
- 6) System transfer; the system is moved to the other end of the block to take measurements of the corresponding vital points and thus the system initiation is repeated.
- 7) Measurement execution; the real coordinate values of the vital points from this other end of the block are measured.
- 8) Recording the measurement results; the measurement results (the dimensional data) are transferred to a database installed in a PC-computer.

Control and Measurement System Evaluation

The suitability of different types of measuring systems related to control software systems to perform the dimensional control task described above can be evaluated on the basis of tests carried out at NASSCO (4).

Table I shows the total costs of performing dimensional control tasks with different type of measuring systems. The figures in the table are extracted from the original report of the field tests at NASSCO. The comparable costs figures of total station type surveying instruments have been added to the table and are based on work done in a major Finnish yard (5).

The results in the summary table show that of different kind of systems, the single man operated Acmeter MC-type optical coordinate meter, which allows direct measurement of the vital points of the block, is most effective in the measurement execution to form a basis for productive dimensional control systems for the final and critical assembly phases in ship production.

The Acmeter MC is the measuring tool of the Acman system, originally developed in close collaboration with major Finnish shipyards to enable building of integrated management systems. The Acmeter has thereby to meet stringent design goals required by the industry:

- 1) Accuracy within one millimetre (0.4");
- 2) Measuring direct to the surface or alternatively to fixed tapes;
- 3) System operated by one single man with real-time coordinate display;
- 4) Software attachments to the CAD and production processes.

The Acman system integration is facilitated by the Accad graphical interface and Acbase relational data base programs. Descriptions of different coordinate measuring systems and of their measuring properties are included in references (3) and (4)

SUMMARY TABLE

BLOCK MEASUREMENT- EVALUATION; TASK EXECUTION TIME AND OPERATING COSTS OF FOUR DIFFERENT SYSTEMS

TASK	ACM/MC	TOT.ST*)	DIG.THEO*)	PH.GRAM
1. SYSTEM SET-UP	8	12	25	15
2. MARRING TARGET POINTS	30		30	30
3. CALIBRATION	6	10	10	
4. MEASUREMENT EXECUTION	25	85	110	30
5. TRANSFER	6	8	15	15
6. CALIBRATION	6	10	10	
7. RECORDING OF RESULTS	5	5		
8. OTHER WORK				130
TOTAL EXECUTION TIME (MIN)	86	2x130 260	2x200 400	255
TOTAL COST(505/60MIN)	72	217	333	213
COST PER POINT(S)	1.4	3.6	5.6	3.6
CAPACITY (POINTS/60MIN)	35	23	15	24

ACM/MC - ACMETER MC,

TOT.ST = TOTAL STATION-type surveying instrument (e.g. Nikon DTM-A5/A10/A20, Wild TACHYMAT TC1000-TC1600),

DIG. THEO = DIGITAL THEODOLITES (e.g. ECDS, Wild Leica),

PH.GRAM - PHOTOGRAMMETRY.

*) THESE SYSTEMS NEED TWO MEN TO TARE MEASUREMENTS.

TABLE I

CONCLUSION

In this report the importance of dimensional control of large block assemblies is emphasized based on discussions, consulting and measurement experiments carried out at more than 20 Western shipyards. The dimensional control is separated from the positional control of the blocks. These two control Problems are, however, overlapping in practical-measurement cases. It is therefore essential to use control methods able to distinguish logically these two different problems.

A dimensional control method relative to a positional reference system is proposed. The method points out the need of real time dimensional control as well as the collecting of measured dimensional data for monitoring and analysing the performance of manufacturing stages. A vital point system, where the target points are marked permanently on the work pieces, is essential when implementing the described control method.

A real dimensional control case of a cruise vessel is shown and measurement tasks listed. The effectiveness of different measurement systems representing various technological approaches are then evaluated in executing the proposed dimensional control problem. The evaluation is based on field experiments done at a number of major West European yards and at NASSCO in USA (4).

Based on the references given and on the requirements of the accuracy control method proposed here, the measurement technology represented by ACMETER MC-type equipment is the most cost effective method of performing the dimensional control task and as an on-site building and inspection tool during all phases of hull block construction. Thus the equipment combined with the methods described here form a good basis for implementation of productive integrated dimensional control systems to meet the accuracy management needs of profitable shipbuilding practices today.

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FIGURES

- 1 The observed accuracy level of the interim product as a function of product complexity. The accuracy level proposed by J.Q.S can be regarded as a reference.
- 2 The positional reference system typically used in ship production when assembling and designing the hull.
- 3 A sketch of a distorted block on the x,z plane. The location of the top deck is negative compared to the nominal position while the x-dimension (length) of the deck is correct.
- 4 A sketch of a distorted block on y,z-plane. The location of the top deck negative compared to the nominal location while the y-dimension (width) of the block is correct.
- 5 Drawing of a cruise vessel block indicating the vital points permanently located on the work piece.

TABLE

- 1 Summary table. Block measurement evaluation, task execution time and operating costs of four different systems.



Technology Survey of Small Shipyards in the Pacific Northwest

VIII B-1

Richard Lee Storch, Member, University of Washington

ABSTRACT

Shipbuilding (large vessels) in the United States has undergone a dramatic change. In the past decade, a major loss of the commercial shipbuilding market became evident. While this trend of a severely shrinking industry has occurred, the importance of small shipbuilding and small shipyards has emerged. This segment of the marine industry appears to be maintaining its market share and has in some areas experienced significant increases. Although the emerging small shipbuilding and repair industry seems to be a significant part of the future of the U.S. marine industry, there are many unknowns concerning this segment of the industry.

Specific questions that exist concerning small shipbuilding can be placed in four general categories. These include (1) the current economic nature of the industry, (2) the current technical nature of the industry, (3) identification of available technology that can be used to improve the industry, and (4) research and development issues that can be pursued to improve the industry.

This paper begins to address each of these issues. Previously employed models are applied in the work. A similar survey approach was used in 1978 to address technology issues in large shipyards. This study, "Technology Survey of Major U.S. Shipyards 1978," was conducted by Marine Equipment Leasing Inc., under contract to the Maritime Administration as part of the National Shipbuilding Research Program. Its goal was to compare existing technology levels in major U.S. shipyards with foreign shipbuilding technology. The results were to be used to help direct and prioritize research and development, and technology transfer efforts to be conducted under the auspices of the National Shipbuilding Research Program.

While the basic model can be used

for this work, the goal would be to compare small shipbuilding technology to existing large shipbuilding technology. Since information on existing technology in large shipbuilding is readily available, both for U.S. and foreign shipyards, the comparison required only the development of information concerning existing technology used in small ship production. The list of items to be included in the survey is based on those in the 1978 survey. In order to achieve a reasonable level of confidence in the survey results, on-site visits are required. These were performed by a single surveyor (the author) on a series of visits to eight shipyards in the Pacific Northwest.

Following completion of the surveys, the data have been compiled and analyzed. Based on these results, a description of the current level of technology application is presented and future needs in the areas of technology transfer, and research and development are identified.

INTRODUCTION

Shipbuilding (large vessels) in the United States has undergone a dramatic change in the past few decades. Following a period of rapid expansion (World War II), the industry experienced a sharp decline that was followed by a relatively stable market. That market was mixed between commercial and military shipbuilding and repair activities. Over the past decade, a major loss of the commercial shipbuilding market became evident. This was in part replaced by the expansion of military shipbuilding to achieve the "600 ship Navy." As that program is winding down, the industry has experienced an unprecedented loss of large shipbuilding market and a number of major shipyards have closed.

While this trend of a severely shrinking industry has occurred, the importance of small shipbuilding and

small shipyards has emerged. This segment of the marine industry appears to be maintaining its market and has in some areas experienced significant increases. Although the emerging small shipbuilding and repair industry seems to be a significant part of the future of the U.S. marine industry, there are many unknowns concerning this segment of the industry.

Specific questions that exist concerning small shipbuilding can be placed in four general categories. These include (1) the current economic nature of the industry, (2) the current technical nature of the industry, (3) identification of available technology that can be used to improve the industry, and (4) research and development issues that can be pursued to improve the industry.

This work is the first step in addressing some of these issues. The primary focus of this paper is topic 2 above. Previously employed models have been applied in this work. The study employed survey techniques and evaluations by independent experts. A similar survey approach was used in 1978 to address technology issues in large shipyards. This study, "Technology Survey of Major U.S. Shipyards 1978," [1] was conducted by Marine Equipment Leasing Inc., under contract to the Maritime Administration as part of the National Shipbuilding Research Program. Its goal was to compare existing technology levels in major U.S. shipyards with foreign shipbuilding technology. The results were to be used to help direct and prioritize research and development, and technology transfer efforts to be conducted under the auspices of the National Shipbuilding Research Program. While the basic model can be used for this work, the goal would be to compare small shipbuilding technology to existing large shipbuilding technology. Since information on existing technology in large shipbuilding is readily available, both for U.S. and foreign shipyards, the comparison would require only the development of information concerning existing technology used in small ship production. The list of items to be included in the survey was based on those in the 1978 survey. This list, however, was modified to be more applicable to small ships and small shipyards. In order to achieve a reasonable level of confidence in the survey results, on-site visits are required. These were performed by the author on a series of visits to yards located in the Pacific Northwest, primarily in or near Seattle.

Following completion of the surveys, the data have been compiled

and analyzed. The goal is to identify future needs in the areas of technology transfer, and research and development. These questions were also a part of the on-site surveys and responses from operators of small shipyards were used.

DEFINITION OF SMALL SHIP PRODUCTION TECHNOLOGY

There are number of specific issues that must be addressed in defining the scope of the study. Three items must be described, including small ship, production and technology. Two of these areas are relatively easy to define, while the third is somewhat more elusive. For this paper, production is defined as any of the hardware related functions that are normally performed by shipyards on vessels, including new construction, overhaul and repair. Although the focus will be on shipyards with the potential to build new vessels, repair and overhaul has been and is likely to continue to be a major part of the business of shipyards. Thus this study will consider technology associated with any of those three types of work.

The Marine Equipment Leasing Inc. study surveyed technology in eight major categories. The categories are listed in the next section. These eight areas were further subdivided to produce 72 elements to be considered. While some of these are not applicable in this study, and others have been added in light of the developments in shipbuilding productivity research that has occurred during the past decade, they form a general bound and thus a definition of technology to be considered. It is important to note that both hardware related technology, such as cutting and bending equipment, and computers, and software related technology, such as scheduling and human resource support systems are included. Thus the definition of technology is broad and includes management, organization, engineering, and manufacturing and repair equipment and hardware. A detailed survey form, outlining all areas considered was used to conduct the survey.

This leaves only the definition of small ship remaining. Unfortunately, this definition is the most ambiguous. Rather than defining a vessel size or type, small shall be presented in terms of small shipyard. The Maritime Administration "is responsible for maintaining current records on facilities, workloads and employment in U.S. private shipyards." [2] That information is processed in two databases, the Active Shipbuilding Base (ASB) and the Shipyard Mobilization Base (SYMBA). These are:

"The U.S. Active Shipbuilding Base (ASB) is defined as privately-owned shipyards that are open and engaged in, or actively seeking, construction contracts for naval and commercial ships over 1,000 gross tons. The Shipyard Mobilization Base (SYMBA) is defined as those facilities capable of constructing, drydocking, and/or topside repairing vessels 400 feet in length and over." [2]

The Maritime Administration listed 19 shipyards in the ASB as of July, 1989. Since then, at least one of those yards has closed. The SYMBA was considered to include 114 facilities, including the 19 in the ASB. The majority of these companies fall in the topside repair category, specializing primarily in repair work on U.S. Navy vessels. The yards in the ASB and/or the SYMBA are not the target of this research.

A list of smaller shipbuilding and repair facilities, throughout the United States, compiled in 1987 by the Maritime Administration, listed over 250 yards in this category. Unfortunately, the Maritime Administration does not consider this segment of the marine industry to be within the scope of its data collection and analysis activities. Thus, no statistical evaluation of these yards is available. [3] Although the definition is not clear, most of these companies worked primarily on "small ships," either in new construction or repair. These are the target of this study. Thus despite avoiding the issue of a firm definition of small ship, the type of yard of interest is relatively clear. Since this study is from only one geographical area, a firm definition becomes less necessary and local knowledge of the yards aids in determining those that are more involved in small vessel production.

TECHNOLOGY SURVEY

The basic categories of the survey come from the Marine Equipment Leasing study. [4] The categories are listed in Table 1 below. Table 2 shows the breakdown of the evaluation technique, including the 8 major categories, the 72 elements within the 8 categories and the 4 technology levels. The surveys included an interview with a designated representative of the shipyard, followed by a tour of the yard. The shipyard representatives were commonly the president, chief engineer or production manager. Interviews

averaged two hours, with the yard tour taking about one hour. The survey form was filled out with notes and impressions. Following the completion of all eight surveys, the elements within each category were rated one at a time for each yard, using the scale of 1 to 4 and rating to tenths. Thus, a yard that was found to be applying technology in a particular element half way between "good" and "better" would be rated at 2.5 for that element. After all elements were rated for all yards, averages per element and per category were computed and are reported.

The specific data sought in each of these categories can be found in appendix B to the Marine Equipment Leasing study. The important categories based on the total survey results will be described in the results section. In addition to these technology categories, a few general questions concerning the relative size and market of the yards were included.

SHIPYARDS SURVEYED

Eight yards were surveyed, but will not be specifically identified due to promises of confidentiality. They were chosen because they represent a good cross section of small vessel production facilities in the Pacific Northwest. The average employment was 225, with the smallest employing 40 and the largest 870. Average yearly sales for these yards was about \$30 million, although one yard had sales about five times this average. The yards vary in work mix from 100% repair to as much as 90% new construction. Vessel types involved include large custom designed yachts, commercial passenger vessels (including ferries), fishing vessels, usually between 50 and 250 feet in length; tugs, barges and government vessels, including navy gunboats, smaller Coast Guard vessels, research vessels and pilot boats. The limitation in size was primarily related to facility constraints, including water depth and haulout or launch capabilities, and work force size and mix. In general, the later limitation is economic, in that the smaller yards preferred not to be limited to one job that consumes the great majority of human and facility resources.

RESULTS AND ANALYSIS

The following series of figures represents the survey results. Figure 1 shows the averages within the eight major categories, and should be referred to during discussion of overall category averages. Figures 2-9

Table 1 Elements surveyed

A: STEEL WORK PRODUCTION		D: SHIP CONSTRUCTION AND INSTALLATION (continued)	
A1	Plate Stockyard and Treatment	D12	Painting
A2	Stiffener Stockyard and Treatment	D13	Testing and Commissioning
A3	Plate Cutting	D14	After Launch
A4	Stiffener Cutting		
A5	Plate and Stiffener Forming	E: LAYOUT AND MATERIAL HANDLING	
A6	Subassembly	E1	Layout and Material Flow
A7	Flat Unit Assembly	E2	Materials Handling
A8	Curved and Corrugated Unit Assembly		
A9	3-D Unit Assembly	F: AMENITIES	
A10	Superstructure Unit Assembly	F1	General Environmental Protection
A11	Outfit Steelwork	F2	Lighting and Heating
B: OUTFIT PRODUCTION AND STORES		F3	Noise, Ventilation and Fume Extraction
B1	Pipework	F4	Canteen Facilities
B2	Engineering/Machine Shop	F5	Washrooms/V.Cs./Lockers
B3	Blacksmiths	F6	Other Amenities
B4	Sheetmetal Work		
B5	Woodworking/Joiner Shop	G: DESIGN, DRAFTING, PRODUCTION ENGINEERING AND LOFTING	
B6	Electrical	G1	Ship Design
B7	Rigging	G2	Steelwork Drawing Presentation
		G3	Outfit Drawing Presentation
		G4	Steelwork Coding System
		G5	Parts Listing Procedures
		G6	Production Engineering
		G7	Design for Production
		G8	Dimensional and Quality Control
		G9	Lofting Methods
B10	General Storage	H: ORGANIZATION AND OPERATING SYSTEMS	
B11	Auxiliary Storage	H1	Organization of Work
C: OTHER PRE-ERECTION ACTIVITIES		H2	Contract Scheduling
C1	Module Building	H3	Steelwork Production Scheduling
C2	Outfit Parts Marshalling	H4	Outfit Production Scheduling
C3	Pre-Erection Outfitting	H5	Outfit installation Scheduling
C4	Block Assembly	H6	Ship Construction Scheduling
C5	Unit and Block Storage	H7	Steelwork Production Control
D: SHIP CONSTRUCTION AND INSTALLATION		H8	Outfit Production Control
D1	Ship Construction	H9	Outfit Installation Control
D2	Erection and Fairing	H10	Ship Construction Control
D3	Welding	H11	Stores Control
D4	On-Board Services	H12	Performance and Efficiency Calculations
D5	Staging and Access	H13	Computer Applications
D6	Pipework	H14	Purchasing
D7	Engine Room Machinery		
D8	Hull Engineering		
D9	Sheetmetal Work		
D10	Woodwork		
D11	Electrical		

Table 2 Evaluation technique

CATEGORIES	ELEMENTS	TECHNOLOGY LEVELS
A STEELWORK PRODUCTION	A1-11	C1 MODULE BUILDING
B OUTFIT PROD. & STORES	B1-10	C2 OUTFIT PARTS MARSHALLING
C OTHER PRE-ERECTION ACT.	C1-5	C3 PRE-ERECTION OUTFITTING
D SHIP CONST. & INSTALL	D1-13	C4 BLOCK ASSEMBLY
E LAYOUT & MAT'L. HANDLING	E1-2	C5 UNIT & BLOCK STORAGE
F AMENITIES	F1-6	
G DESIGN. DRAFTING. PROD. ENG'RG.	G1-9	
H ORG. & OPERATING SYS.	H1-14	
8 CATEGORIES	70 ELEMENTS	4 TECHNOLOGY LEVELS

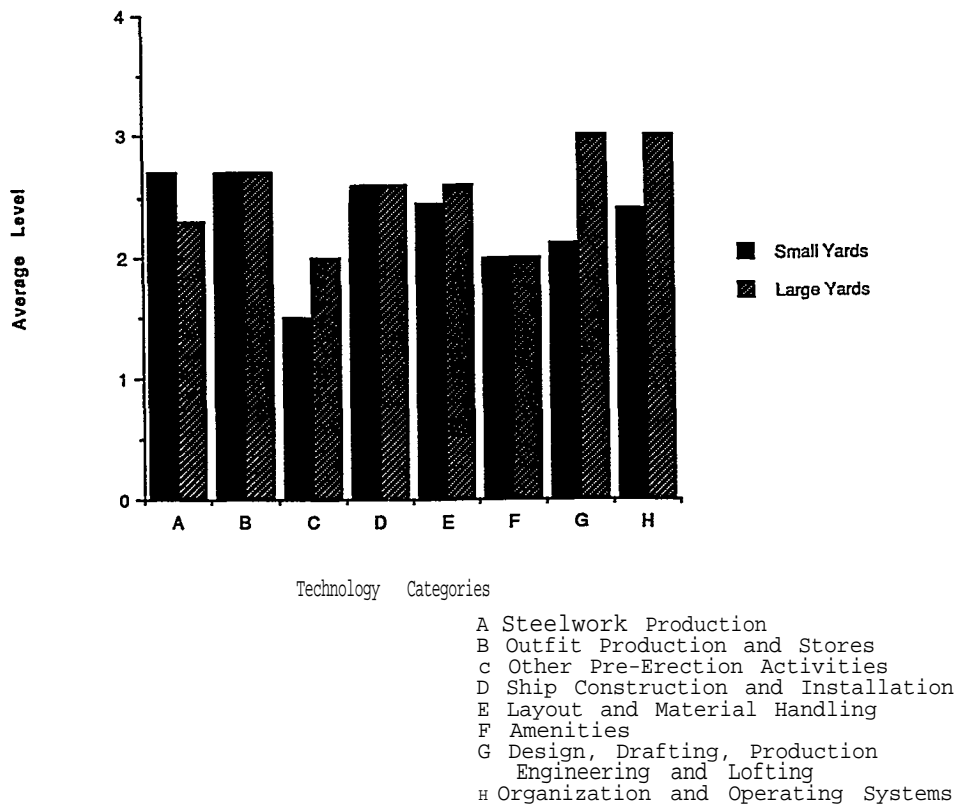


Fig. 1 Average Technology Levels by Category

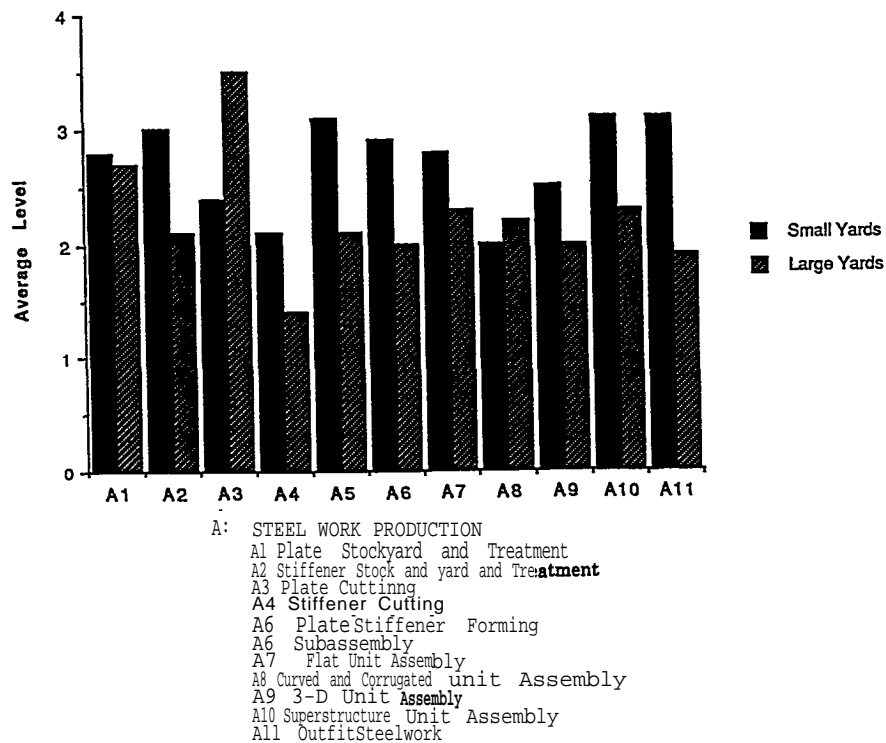


Fig. 2 Average Technology Levels in Steelwork Production

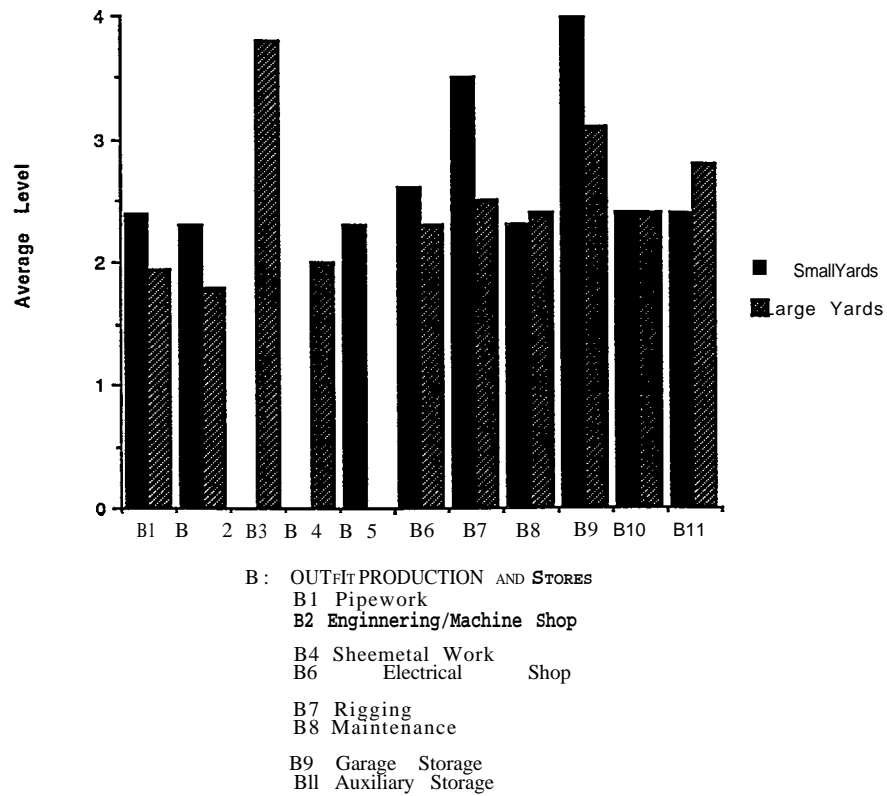


Fig. 3 Average Technology Levels in Outfit Production and Stores

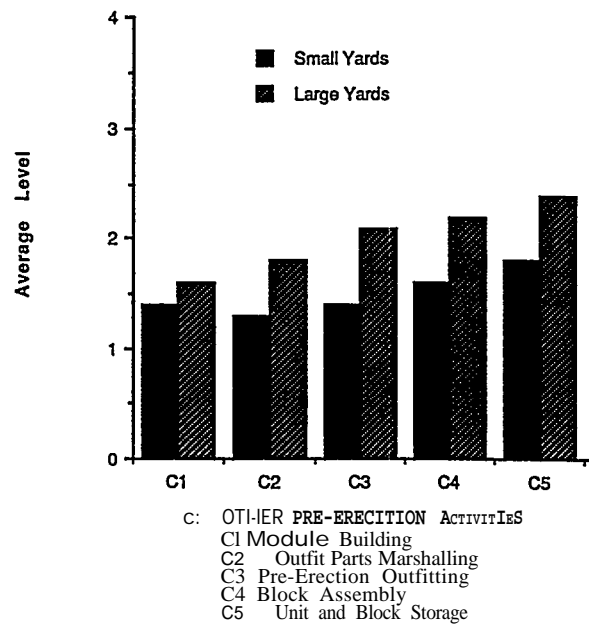


Fig. 4 Average Technology Levels in Other Pre-Erection Activities

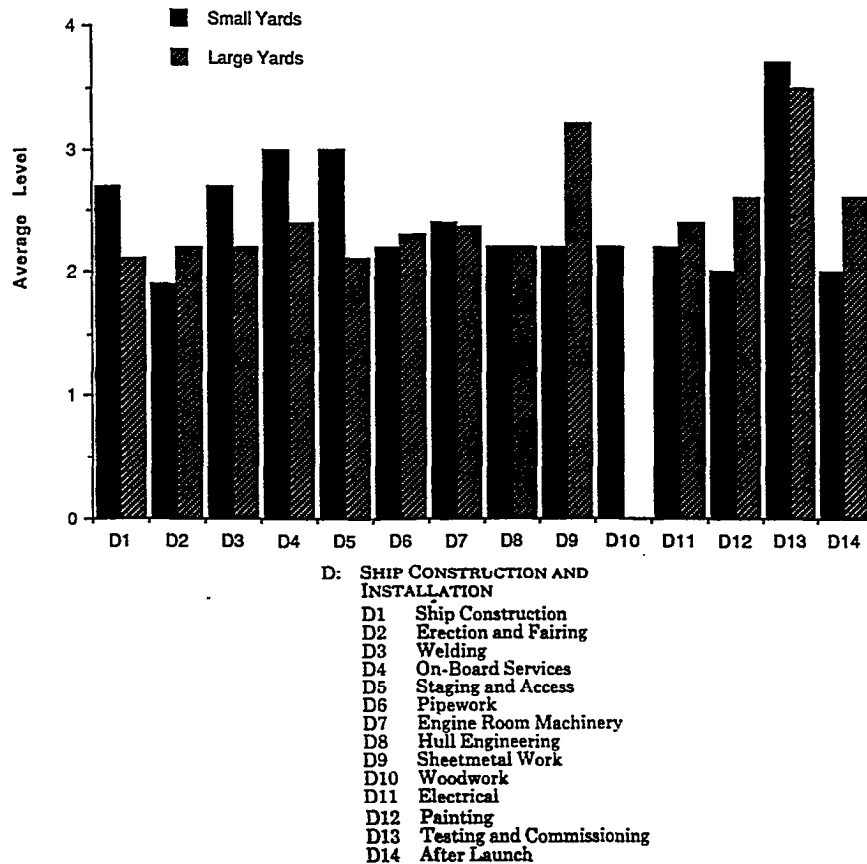


Fig. 5 Average Technology Levels in Ship Construction and Installation

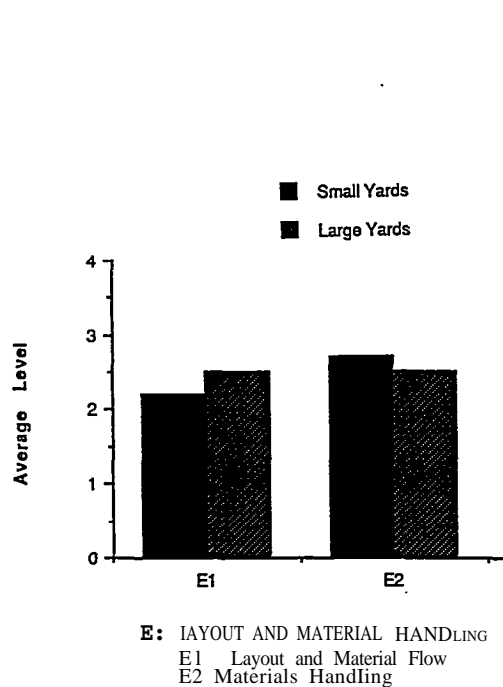


Fig. 6 Average Technology Levels in Layout and Material Handling

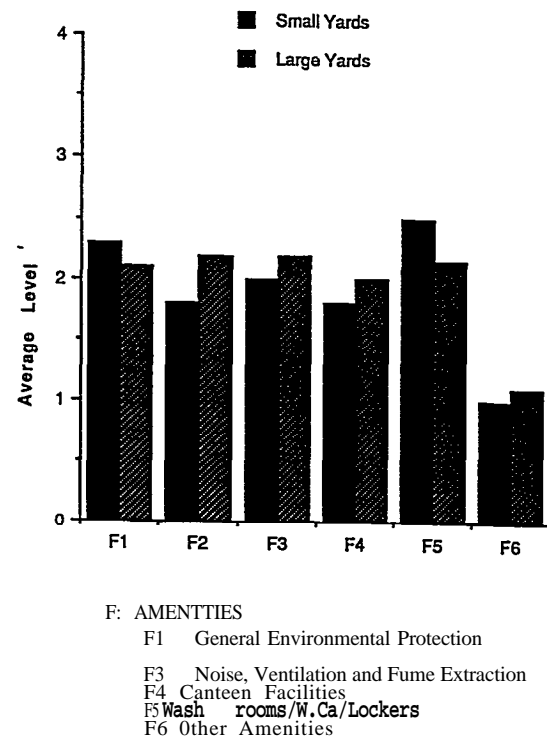


Fig. 7 Average Technology Levels in Amenities

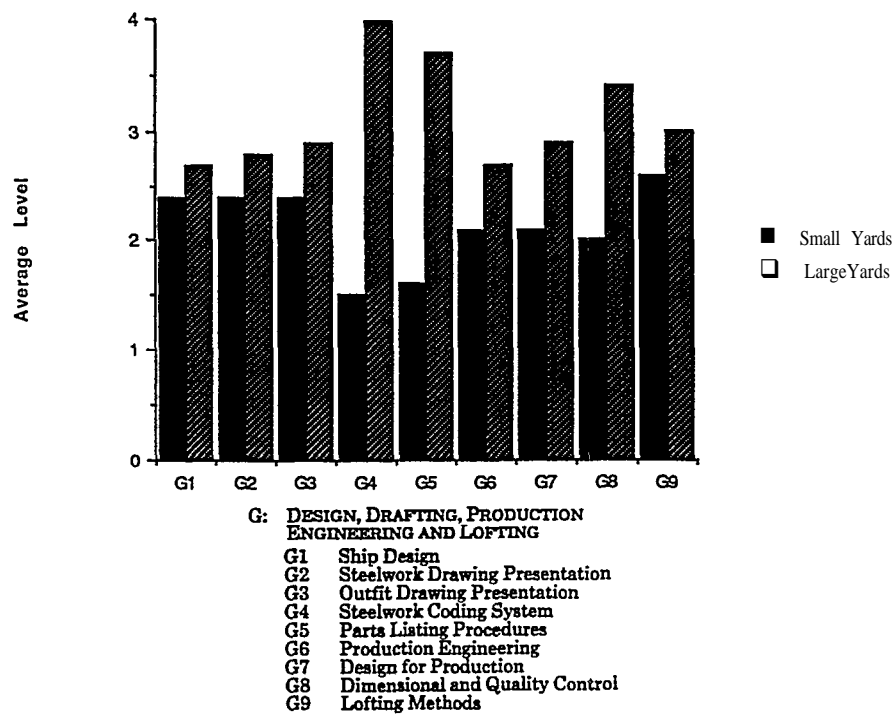


Fig. 8 Average Technology Levels in Design, Drafting, Production Engineering and Lofting

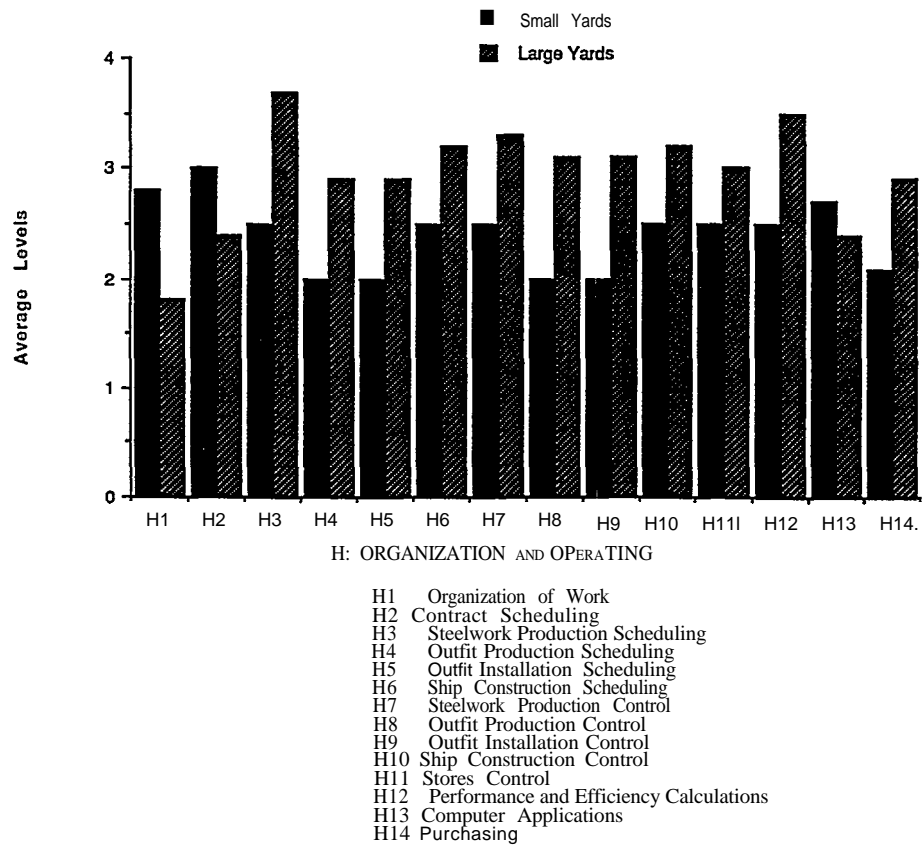


Fig. 9 Average Technology Levels in Organization and Operating Systems

show the results for each of the 72 items in the eight categories, and should be referred to during discussion of categories A-H, respectively. The large U.S. shipyard ratings are taken directly from the Marine Equipment Leasing study as reported in 1980. [4] Although these do not represent current practice, they are presented unchanged to provide a basis for comparison without adding an additional uncertainty. In each case, the average level of technology application in the small yards surveyed is compared to the author's rating of the current best application in the world. Considerable documentation of the world's best technology has been accomplished under the auspices of the National Shipbuilding Research Program, including hardware and software, applied to new construction and overhaul and repair. Reports produced for that program and papers that appear in the Journal of Ship Production are the primary source. A comprehensive list of the major sources is presented in the NSRP Bibliography of Publications. [5] Although it would be possible to extend the amount of statistical evaluation of the results, the analysis will be limited to comments about each of the eight categories, and then some general conclusions.

Category A is steelwork production. In this analysis, other structural materials, such as aluminum, are also included in this category. Fiberglass was not employed as a structural material in any of the yards surveyed. The overall average is 2.7. This compares to a 1980 large shipyard average of 2.2. In this category, there has likely been substantial improvement in the large yards over this decade. The small yards exhibit relatively good technology in terms of work organization for producing sub-assemblies, and flat block assemblies. In particular, most yards build superstructures as independent structures and then land them on board. Fixed or variable (temporary) locations are often established for producing steel sub-assemblies and flat blocks. In general, these approaches are more likely to be used if more than one vessel is being built and they are commonly only applied to new construction. There is an expected weakness in plate and stiffener cutting and forming, when the work is done in the yards. However, there is a strong tendency to subcontract this work. That results in the ability of the small yard to take advantage of higher levels of technology application by the subcontractors, without having the expense of high technology equipment in the yard. These yards also commonly work on vessels with little or no

curved or 3D block categories. Consequently, despite a low capability in these areas, the paucity of work required negates this as a serious deficiency.

Category B is outfit production and stores. Here again, subcontracting dominates. In particular, sheet metal, electrical, some rigging and some rolling stock maintenance are subcontracted. Category B3, blacksmiths or forge, does not apply and was not considered. The overall average for the small yards was 2.7, which compares directly with the 1980 large yard average of 2.7. For the small yards, the specific elements that were below this average (although just slightly) were pipework, machine shop work, woodwork, plant maintenance and both general and auxiliary storage. The first three reflect the general job shop work organization, i.e. a lack of the application of fixed work stations and group technology, coupled with generally older and less sophisticated equipment. The equipment is probably not a significant problem. There were a few significant exceptions, generally where a shipyard has established a specialty in order to obtain a market. A major example of this is a machine shop section set up to work on tailshafts, not only for shipyard specific work but as a subcontractor to other yards and vessel operators. Concentration in wood work is another example, both for wooden vessel repair, overhaul or construction and for cabinetry and finish work. The philosophy of the majority of these yards toward plant maintenance was somewhat short of "scheduled and planned." Instead, most maintenance was "fix it if it breaks", and only occasionally was regular scheduling of maintenance or improvement considered. Naturally, equipment that requires regular maintenance for safety regulation requirements, such as cranes, is handled as necessary. Finally, the physical storage capabilities, while generally adequate, reflect the storage philosophy, which will be discussed in category H.

The single worst category, both for small yards and in the 1980 large yard results is other pre-erection activities. The small yards were rated at 1.5, compared to 2.0 for the 1980 large yard survey. This category documents the work done away from the vessel, either pre-erection for new construction, or before re-assembly for repair and overhaul. Much of the small yard work is repair and overhaul. These activities were not included in the 1980 large yard survey. Had they been, the large yards would have likely rated closer to the current rating of the small yards. The yards, on

average, do not employ significant amounts of the best technology for improving productivity in any element in this category. Lowest ratings were given for pre-erection outfitting and outfit parts marshalling. There was no evidence of any on-unit outfitting and relatively little on-block outfitting. Parts marshalling was generally either worker or supervisor responsibility, and commonly done associated with work orders that are too large in both content and duration for effective material or production control. Similarly, block assembly and block storage away from the erection site are the exception. The vessel size, limiting the value of a large number of block breakdowns, and facility size constraints contribute to the lack of activity in these areas. Additionally, repair and overhaul work was uniformly treated as a one-of-a-kind job. Consequently, no formal work rationalization, leading to repeatability was evident. A result of this is on the spot planning of work, which precludes the accomplishment of any significant amount of work away from the vessel.

Category D includes more effort than should be required because of the lack of pre-erection activities. The small yard average is the same as the 1980 big yard average, 2.5. There is considerable variation within the elements in this category. Hardware related elements generally scored well. These include welding, on-board services, and staging and access. As might be expected, the level of technology application in these hardware items is not as high as in large shipyards, but the level appears to be generally appropriate given the type of work and investment capability of small shipyards. Also, the erection process and testing and commissioning procedures rated quite high. The remaining categories, relating to on-board outfit and painting work, generally rated low. The great majority of this work occurs on-board, usually after access is greatly limited. Coordination between outfitting activities is commonly scheduled by a project manager, usually on a daily or weekly basis, with relatively little pre-planning. There is no indication of any planning before design, and coordination of subcontractors did not seem to include consideration of the impact of that work on the overall productivity of the project. A small yard advantage, to be discussed in relation to category H1, is the combination of work skills in individuals or small work groups. Thus, the various types of outfit work get some de facto coordination since the same people are involved in performing the work. The small yards,

like the large ones, show poor performance in erection and fairing practice, with no modern dimensional control and margins provided for erection site fairing. Here again, the job shop mentality leads the managers away from techniques that might improve productivity. Line heating as a regular distortion removal tool was not in evidence, although the use of heat for fairing and after erection distortion removal was observed.

Yard layout and material flow for small yards is generally acceptable (category E). Size is a definite advantage here. In most cases, the yard layout and material flow has developed over time, usually without an overall plan as a goal to be achieved. Additionally, most small yards have grown around existing buildings, that are not moved or replaced to improve overall flow. Thus there are some constraints and lack of planning evident, but, despite the lack of formal technology application, no major problems were identified in this category.

Category F deals with the work environment and amenities provided for the workers. Both the large and small yards score poorly in this category, 1.9 for each. This seems to be a feature of U.S. shipbuilding. The best scores are for basic personnel services, including washrooms, w.c.'s and lockers. The provision of protected work spaces, with good lighting, heating and ventilation is not common practice. The general work organization, concentrating work on-board, is in part responsible for this outcome. Where protected work spaces exist, the work environment provided is appropriate. In the Pacific Northwest, protection from rain is useful, but substantial heating is not required. Thus, subject to improving work organization, current work environment provisions seem appropriate. The small yards tend to provide almost no company wide outside activities. These functions seem less required, however, given the small size of the work force. Company culture, however, seems quite apparent in these shipyards. Employee loyalty seems to respond more to these company culture patterns, associated with the working environment. Thus additional formal amenities outside the working conditions would not seem to be required to achieve a satisfied and contributing work force.

Category G is an extremely critical one, and one in which current technology application and future directions are quite different between small and large yards. The average rating of 2.1 for the small yards is considerably below the 3.0 given to the

large yards in 1980. Additionally, there is an extremely wide variation between the small yards surveyed. Among the major differences is the size of the design staff and the related philosophy of how design is accomplished. The variation here is from a single owner/engineer as the only technical employee to a complete in-house design and engineering staff, with all levels of staffing in between. Related to this is the type and detail of design and engineering information that is employed. These are two related but independent considerations. For example, incomplete and inadequate engineering information can be the product of an in-house or external engineering effort. The opposite can also be true. Thus the critical factor is the determination of what and how information is developed and communicated. On average, ship design capability and drawing presentation rated 2.5 for the small yards. This level seems appropriate for the markets served. Similarly, lofting capabilities, either in-house or from a subcontractor are generally acceptable, with a clear trend to greater direct generation of lofting information from computer aided design (CAD) systems. The remaining elements, including standardization of information presentation (coding and parts listing), production engineering, design for production, and quality control rate no better than 2.1. There was no apparent movement toward planning before design, i.e. formal production input before design. Similarly, production engineering is only informally applied as seems appropriate for a particular job. Flexible standards are not evident in the small yards, unless a series production effort is underway. Additionally, the quality philosophy applied, like that evident in most large shipyards is the archaic approach of after production quality assurance, rather than in-process and pre-process quality control. These changes in corporate culture are independent of company size.

The final category is organization and operating systems. Here again, the small yards rate considerably lower than the 1980 large yards, 2.4 versus 3.0. Within this category, the elements for which the small yards rate well include organization of work, contract scheduling and scheduling and control of steel work. Although there is some variation, the major consideration in rating organization of work is the ability of the work force to combine work categories in a single worker or work team. Due to size, most small yards surveyed employ multi-disciplined work teams. Work rules, even in union shops, did not appear to

constrain effective organization of work. As mentioned previously, planning is the constraint. Additionally, all the small yards surveyed did effective master scheduling. Below this level, however, only steel work schedules tended to be produced in enough detail to aid in production control. As in many other shipyards, outfit work is considered after steel work, not coordinated with steel work. Control and scheduling below the master schedule level is generally heavily dependent on the project manager. While this is generally effective in terms of completing a project, it makes company learning and improvement difficult. Similarly, since detail planning and scheduling is performed by the project manager while the work is underway, performance and efficiency calculations are general. In most cases, these were the traditional "black book" numbers maintained by the president or chief estimator. While these are effective for some types of projects, they make estimating new or different work extremely risky. As discussed in category B, facilities for storage of stock and auxiliary items were generally adequate, given the stores philosophy employed in the yards surveyed. Standard stock items are commonly monitored and ordered by the shop involved. The standard low level order point system with a fixed (economic) order size is used. No control beyond this is common. Allocated stock items are commonly ordered by the project manager, or supplied by the owner. Storage is usually in a separate location, on a project by project breakdown. No use of early material identification procedures or an allocated stock category was evident in the surveys. Nearly all yards indicated the traditional difficulties imposed by uncertainty and delay in the receipt of material. Most of the smaller yards use computers adequately, including payroll, some CAD applications, some scheduling applications and some material applications. Computer capabilities, however, are available far beyond the average application in the small yards. Finally, purchasing systems are generally poor, with little repeatability and typical late delivery and expediting problems. This item is closely related to stores control, as described earlier.

CONCLUSIONS

There are a series of general conclusions that can be drawn about technology application in small shipyards. Hardware technology is generally at a lower level than in big shipyards. This is partially evident

from looking at categories A and B, although this deficiency is largely overcome by the extensive use of subcontractors and by arrangements with vendors. For example, relatively little advanced plate cutting and forming capability exists in most of these yards. However, subcontractors are used to provide numerical control (N/C) cut steel, where a significant number of steel parts are needed. Steel is generally received already wheel-abraded and primed, and thus no facilities for performing this work are found. Also, the vessel size and typical design (hard chine and developable surfaces predominate) constrains the development of facilities for forming and assembling blocks by problem category. The curved block and 3D block categories employed for large vessel construction do not apply for small vessels. Most of the parts fabrication and assembly for outfit is also subcontracted, including sheet metal, joinery, and electric work. Ten painting is subcontracted. As mentioned, a major exception is the development of a specialty in certain processes, such as tailshaft repair, woodwork, etc. These hardware constraints do not seem to be a major impediment to the improvement of productivity. In fact, substantial use of subcontractors can provide a significant advantage in lowering overhead and capital requirements, and in providing a means of responding to workload variations. However, scheduling and control of the subcontractors is a critical piece of the manufacturing system and must be carefully managed to obtain maximum benefit.

Although varying amounts of understanding of group technology or zone oriented approaches was exhibited, the "opportunities" for the application of this approach are considered to be limited by these yards. Construction or replacement of superstructure, including wheelhouses, is often done using a zone oriented approach. This is generally the most extensive application of this technology. The use of on-unit and on-block outfitting is far short of what is possible. The possibilities of applying this technology for those yards doing new construction seem quite apparent. Zone outfitting approaches, while primarily documented in applications of large ship construction, offer significant productivity improvements in any project in which complicated work in a congested area leads to competition for space in which to work. [6,7] Clearly small vessels meet this criterion, and proportionally exceed the benefits that accrue in larger shipyards.

There are three prerequisites to the application of zone technology in small shipyards. These prerequisites are the same as those required for large shipyard application of zone technology. These include the establishment of a product work breakdown structure (PWBS), the involvement of the yard in determining and obtaining sufficient information to adequately plan and control the production process, and the adoption of shipyard specific flexible standards. [8]

First, the yard managers must "conceptualize" a product work breakdown structure. Large yards have the luxury of introducing a PWBS by physically establishing work flows for the various work categories. Small yards probably cannot afford the space associated with this physical rearrangement. Thus a "conceptual" PWBS would imply a typical work flow that is organized by problem category for each job. Some work would be real flow and some virtual flow, organized to fit into the facility. Although some variations would occur based on the project, the conceptual framework of the work organization should be documented, repeatable and recognizable.

The second prerequisite involves information generation and management. Currently, technology application in these management areas, including design, scheduling, production control and material control is at a relatively low level. The choice of how to improve these areas is not easy, however. Most small yards have relatively few people that participate in these management functions. This results in both low technology utilization and low overhead costs. The most common number of design engineers in the yards surveyed is one or two. Thus much design is done by outside naval architects. The ability of a small yard to become involved in the development of a build strategy as part of design is thus a function of the understanding of zone logic on the part of the naval architect, the owner, and the yard naval architect. This has often resulted in little input from the yard during design. Instead, yard process and design preferences are generally only considered after selection of the yard by the owner and then during contract negotiation or after the contract award. The opportunities for the development of a build strategy are therefore severely limited. [9] Thus a new approach is required. One possibility is an extension of the use of subcontractors that has been effectively applied in production. In this case, the subcontractor would be a naval

architectural firm. However, the arrangement must be more like that employed in hiring a production subcontractor, where the shipyard develops a relationship with the naval architectural subcontractor, including maintaining information about yard capabilities, preferred build strategies, etc. This service should not involve any conflict of interest concerning the naval architect also working for an owner, with the possible exception of that naval architect also being an owner's representative during production. While such an arrangement would require careful consideration on the part of all parties, long term benefits would be obtained by owners, shipyards and naval architects. An important aspect of this system would be documentation of build strategies for the yard. Competition would, then be for a vessel with given capabilities, that would be achieved by slightly different designs tailored to shipyard specific design details. As always, price and schedule would be the main decision variables. This system would reduce the costs associated with the current procedure of independent design, bids on a contract design package, negotiation between a yard and an owner, and then development of working drawings. [9] Naturally, those small shipyards that currently have in-house naval architectural capabilities can employ that capability to develop build strategies before design for new projects.

Availability of production planning and scheduling, especially before design begins, is uncommon. Planning and scheduling rarely goes beyond a key date master schedule. Ship superintendents then develop plans and schedules in daily or weekly meetings with production supervisors. Progress and cost returns are rarely developed in a formal manner, and thus this type of data commonly only resides in the "black book" of the experienced shipyard manager. A system that develops and maintains this type of information is essential to monitoring and improving productivity, with the ultimate result being lower cost, a more competitive shipyard and more accurate cost estimates. [9] The use of productivity indicators has proven to be an effective means of maintaining this type of data base. [10] While there will be some added cost associated with the implementation of such a system, its use will reduce cost and require less effort than is currently expended by the traditional superintendent/project manager driven system.

The third prerequisite deals with the material purchasing and control systems in these yards. Small yard

technology application here also lags behind better marine practice. Since the most competitive shipbuilders concentrate on material control as a critical part of the management process, this is an area of considerable concern. Simple inventory and material control software systems can be employed easily and efficiently, if work is controlled repeatably through the application of a PWBS. A proven technique for obtaining control over material and design is through the adoption of shipyard specific flexible standards. [11,12] Here again, a subcontractor type relationship with a naval architect can aid in the development of such a series of standards. The establishment of a system of shipyard specific flexible standards is a data intensive effort. Use of CAD capabilities can greatly facilitate the use of standards. The achievement of such a file for small shipyards is not likely to occur quickly, but with adequate computer hardware or a naval architectural subcontractor relationship, flexible standards can be achieved over time.

To this point, much of the discussion in this section has its most obvious application in new construction. When consideration of repair and overhaul is included, the common response is "every job is different." To the contrary, recent documentation is showing the applicability of these concepts to repair and overhaul. [13,14,15,16] Since this part of the business is so critical to most shipyards, extension of the PWBS to repair and overhaul in small shipyards is a critical step to improving competitiveness. Current thinking concerning the application of a PWBS to repair and overhaul is that it is certainly effective if design/engineering effort is required. Whether such a work organization is optimum for "regular" repair work is as yet unproven.

Small yards do exhibit better worker organization than larger U.S. shipyards. Both union and non-union yards employ flexible work arrangements, including multi-skilled work groups and multiple craft workers. This capability is primarily used in on-board work, both for installation and repair. This more flexible approach to work rules offers significant productivity enhancing opportunities. The achievement of this flexibility in work is a major advantage for small yards, achieved through the excellent management efforts of small yard operators. Combined planning of structural and outfit work would greatly increase the ability of small yards to take

advantage of this flexibility in work organization.

There are a few additional items uncovered in this research that are worth noting. An area of interest and concern that was not specifically covered in the surveys, but was mentioned in many of the interviews, is the impact of environmental protection requirements. While all small shipyard managers indicated an understanding of the needs and the inevitability of increasing requirements, most felt that a means of sharing the burden associated with improvement here would be required. A second impression, mentioned previously but worth repeating is the increasing trend to subcontracting. In the long run, small shipyards could become assemblers and launchers, with the remaining work all being done by subcontractors located away from the expensive and generally prime waterfront property occupied by shipyards. This trend is apparent worldwide, and involves large and small shipyards. An inescapable conclusion associated with this trend is the increasing shortage of skilled shipyard workers. Given the poor prospects for job security, the inability to attract a significant number of new trainees is not surprising. It is disturbing, however, for if the industry is to survive, a trained work force is essential. Thus both training programs, and a commitment to the survival of the industry are required. The most important commitment to survival must come from the industry itself, by demonstrating substantial and continuing productivity improvement. Only then can a viable base be established and sustained.

Finally, all the small yards that were surveyed are successful shipyards. Most have been in business for many years, usually at least 30 years. They are run by talented, dedicated shipbuilders. But they are all aware of the difficulties faced by the marine industry in the U.S. and all have experienced difficult swings in workload. It is with some humility that the author offers the above suggestions. The goal is to stimulate thought, discussion and analysis of different approaches that should be considered as a means of strengthening and improving the small shipyard segment of the marine industry and hopefully the entire marine industry.

FUTURE RESEARCH AND TECHNOLOGICAL NEEDS

The conclusions section above provides a series of suggested areas to be considered by small shipyards as a means of improving productivity and competitiveness. None should be tried

without study of costs and potential effectiveness. Initially, a more complete sample of small shipyards throughout the U.S. would be required to indicate the generality of these findings. While informative, a sample size of eight of perhaps 250, representing only one geographic region, is certainly not conclusive. Additionally, more than a single surveyor and analyzer might add further weight to these findings.

A primary suggestion is the establishment of a PWBS for small shipyards. The initial suggestion is to employ a "conceptual" PWBS. This suggestion certainly begs for further definition and study. Research sponsored by the Maritime Administration enabled the first two large U.S. shipyards to implement a PWBS. A similar program for one or a consortium of small shipyards would seem prudent. Similar public documentation and information transfer would be an essential part of any such approach.

The goal of enabling small shipyards to develop a build strategy and therefore plan before design was also recommended. While there is a body of experience in this approach developing in large vessel construction and overhaul, here again further consideration of the level and details of the effort needed for small vessels and small shipyards is required. Part of the effort for large shipyards involved not only internal learning, but also understanding of the new approach by owners. Experience of some owners in dealing with Japanese shipbuilders facilitated some of this requirement. Most small vessel owners do not have similar overseas experience, and thus the effort will be more significant in providing an understanding of shipyard and owner needs in this new approach. Additionally, there is considerable need for an in depth study of the implications of the long term naval architectural subcontractor relationship proposed. Technical, financial, and perhaps legal considerations must be investigated. In this area, research could be performed to develop a build strategy, block breakdown, typical outfit units, etc. for a generic small vessel design. Such an effort would provide documentation of the type and quantity of outputs required for small shipyards.

The issue of standards for the U.S. shipbuilding industry is still in need of substantial action. Of primary importance is the idea of flexible standards involving outfit units, such as those described in [12]. Standard

items are of considerably less value in improving productivity. CAD development is the major requirement in this area. While computer capability certainly exists, programs that maximize the effectiveness of flexible standards are not common practice. Work in this area may involve some basic research, but more likely can be accomplished and distributed by a demonstration project. This use of the CAD system offers a critical productivity improving opportunity.

Material definition, purchasing and control are critical parts of any effective manufacturing system. Given the difficulties with the marine supplier base, these systems become even more critical. Little new research is needed here, since proven approaches for all of these aspects of material management are available and applied in many industries. These systems can help deal with supplier and material availability problems. There is ample software, that runs on personal computer size machines, available to aid small shipyards. Thus only a technology transfer effort is required to achieve improvements in this area.

Finally, the extension of product orientation to repair and overhaul remains a critical research product. On-going work has begun to describe the principles of a PWBS for large ship overhauls. Extension of this work into small vessels and into repair of all size vessels is an important next step.

Concerning the two conclusions that were not directly sought in the surveys, some clear research requirements emerged. While there are already considerable efforts underway relating to responding to the need for environmental protection (in particular in NSRP Panel SP-1), there will undoubtedly be continuing research requirements. Additionally, training programs coupled with attempts to attract new trainees to the industry are needed. Here again, efforts are underway (NSRP Panel SP-9). The commitment to productivity improvement must come from each shipbuilder. As a first step, a self evaluation of current status using the elements of the survey would be valuable. Familiarization with the NSRP literature is also a useful beginning. Reversing the downward slide of our industry is a worthy but difficult task, requiring thinking in the long term and employing new approaches.

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Strength Properties of Drydocking Timbers and Blocks

VIII-B-2

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ABSTRACT

Knowledge of the strength characteristics of docking block timbers is a key element in safely drydocking ships. Such knowledge has become especially important for the Navy, because of changes in Navy ship design, coupled with heightened safety concerns regarding seismic loading. Although, over the years, timber strength knowledge has evolved to a general level, it has never reached the detailed level required to meet today's needs. This paper describes a study to gain timber strength knowledge at the detailed level by testing actual docking block timbers. The tests were conducted on individual timbers, timbers formed into layers, and timbers within full-sized docking block build-ups.

LIST OF ACRONYMS

DTRC	David Taylor Research Center
FSPL	Fiber Stress At Proportional Limit
LVDT	Linear Variable Differential Transformer
MIL-STD	Military Standard
MOE	Modulus of Elasticity
NAVSEA	Naval Sea Systems Command

INTRODUCTION

For most of the history of drydocking ships had short bow and stern overhangs, wide keels, and relatively uniform longitudinal weight distributions. When drydocked, these ships were supported by a number of low, timber, docking blocks that ran the length of the keel (1,2). Each block bore approximately the same, relatively modest load. More recently, and especially following the Second World War, ships have changed. Today's ships, in particular the combatants, typically have long bow and stern overhangs, narrow keels and areas of high weight concentration. In addition, they may have sonar domes that extend below the keel. These changes have impacted docking blocks. The long bow and stern overhangs increase the loading at the blocks closest to the overhangs; the

narrow keels increase local loads on docking block soft caps; the high weight concentrations increase loading on particular blocks; and the sonar domes that extend below the keel can require high, potentially unstable, build-ups of docking blocks. Coupled with these changes are safety concerns with seismic loading (3).

In recognition of these matters, in the late 1980s the Naval Sea Systems Command (NAVSEA) contracted Associated Forest Products- Consultants, Inc., to conduct a study to provide definitive data on the compressive strengths of timbers that are used in docking blocks for U.S. Navy dry docks. The study comprised testing actual docking block timbers in the University of Washington Structural Research Laboratory and analyzing the results of those tests. This paper describes the study and its procedures, results, conclusions and implications.

NAVY DOCKING BLOCKS

All Navy drydocking facilities employ docking blocks as the means of supporting ships in dry dock (2). Each Navy shipyard typically has over 1,000 blocks and certain Navy shipyards have over 3,000 blocks in service. Figures 1-3 provide examples of Navy docking blocks. Figure 1 illustrates an all wood keel block; Figure 2 shows a concrete and wood composite block build-up (the Navy Standard Composite Block); and Figure 3 illustrates a sand block. All of these blocks include timber in their construction, and in all cases the timber is loaded perpendicular to the grain. Oak and Douglas fir are the wood types that are most commonly used in these docking blocks.

PREVIOUS STUDIES

Wood, when used for structural purposes, is almost always stressed parallel to the grain. Docking block timbers are a notable exception: they are loaded and stressed perpendicular to the grain. Figure 4 illustrates these two

loading orientations. As might be expected, relatively little is mentioned in the literature about wood which is loaded perpendicular to the grain. However, some studies have been published that address perpendicular loading in general and keel block loading in particular. The following paragraphs describe examples of these studies.

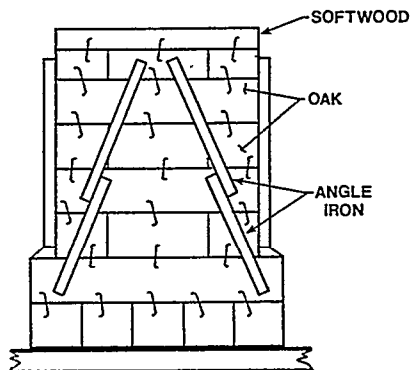


Figure 1
All Wood Keel Block

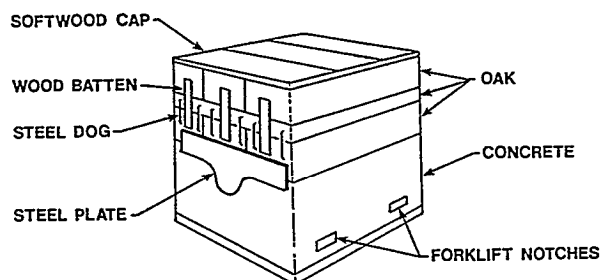


Figure 2
Composite Block Build-Up

Two landmark studies were conducted as a result of the failure of the docking blocks under the USS South Carolina on May 29, 1924 at the Philadelphia Navy Yard (4). To determine the cause of the failure, compressive tests on docking blocks were carried out at the U.S. Department of Agriculture Forest Products Laboratory and the Washington Navy Yard. The blocks were comprised of oak timbers, each measuring 35.6 x 35.6 x 121.9 cm (14 x 14 x 48 inches). The tests examined the compressive strength of the timbers and considered variables such as high block instability, moisture content, duration of loading and timber defects. Full size timbers and model blocks 3.2-5.1 cm (1.25 to 2 inches) square were tested. Selected results of the tests

are presented later in this paper.

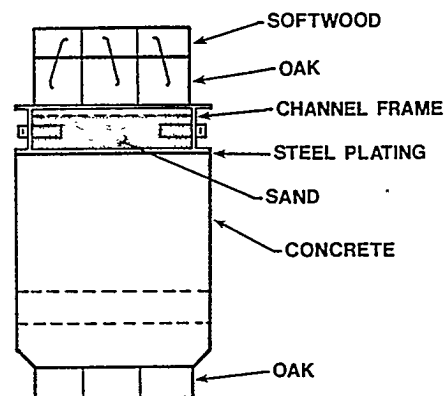


Figure 3
Sand Block

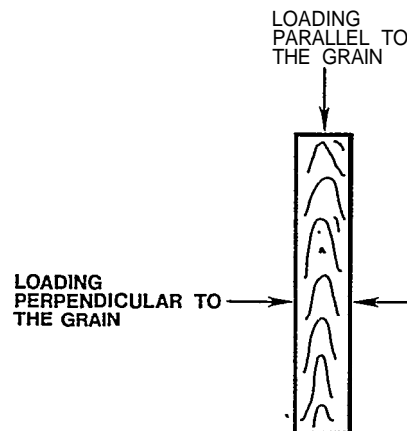


Figure 4
Wood Loading Orientations

Other studies have developed standard tests for wood strength. In the standard transverse compression test for wood, the load is applied through a 5.1 cm (2 inch) wide steel plate across a 5.1 x 5.1 cm (2 x 2 inch) clear wood specimen 15.2 cm (6 inches) long. Test results are used to develop recommended bearing stresses for joists, beams, and stringers loaded perpendicular to the grain. Data published in the *Wood Handbook* (5) for all commercial species are based on this test, described in ASTM D-143-52 (6). Other studies have used the same 5.1 cm (2 inch) bearing plate, or only a somewhat wider one (13.3 cm, 5.25 inches) to determine compression strength perpendicular to the grain values for Douglas fir and other structural species (7). Because these compressive tests were performed with a bearing plate, the modulus of elasticity (MOE) cannot be

determined. Nor are MOE values in compression perpendicular to the grain available elsewhere in the literature.

There is a limited record of earlier efforts to deal with keel block properties and problems. The "History of the Development of the MIL-STD for Drydock Blocking Systems" (8) mentions that a major gap in the proposed MIL-STD is lack of data on large timbers. Also from the same reference, comments on the draft of NAVSEA's Proposed Drydock Blocking Systems MIL-STD by various shipyards reveal an inconsistent understanding of allowable stresses on keel blocks.

Tarr (9) tested small samples of Douglas fir, white pine, and white oak to failure under compression perpendicular to the grain in full bearing and concluded that the fiber stress at proportional limit (FSPL) for the softwoods was about 1,720 kPa (250 psi) and for the white oak was about 4,140 kPa (600 psi) (the fiber stress at proportional limit, or FSPL, is where the load-deflection curve departs from a straight line).

Naval Ships Technical Manual, Chapter 997 (10) cites the load-deflection curve for a "typical composite block" which indicates a FSPL of about 3,450 kPa (500 psi). This reference also lists deflection data for tests on eight composite keel block builds (these tests will be discussed later in comparison with results of the present study).

Bath Iron Works instrumented two keel blocks to determine block loads during drydocking (11, 12, 13). The instrumented blocks measured vertical loads under two ships, the USS Scott (DD-995) and the USS Conolly (DD-979). Load cells were inserted in one keel block for each ship, replacing a 15.2 cm (6 inch) layer of oak in an oak and concrete composite block. Each load cell was comprised of four low profile 152 tonne (150 ton) capacity hydraulic jacks placed between two steel plates. The DD-995 load cell had a 1.22 meter (4 foot) length along the keel, while the DD-979 load cell had a 1.83 meter (6 foot) length along the keel. The load cell measurements helped to validate a drydock block loading computer program.

Crandall (14) tested one red oak and four softwood timber specimens and determined FSPL and MOE for each specimen. The FSPL ranged from 1,520 kPa (220 psi) for white pine to 3,450 kPa (500 psi) for Douglas-fir and was 4,830 kPa (700 psi) for red oak. "Wet" specimens in these tests produced the same results as "dry" which probably reflects an inadequate period of water immersion before testing. Crandall's work additionally showed that continued loading above the FSPL produced a "compressive range" where small increases in loads resulted in dramatic increases in deflection (indicating an extremely

low MOE); and if loading continued, a point was reached where load increased rapidly again for a small increase in deflection.

Palermo's investigation of pressures on keel blocks during the drydocking of three aircraft carriers (15) described the use of specially designed load cells consisting of fluid-filled "metalwafers" in selected keel blocks to record actual block loads in comparison to theoretical projections. Palermo showed that the maximum recorded block pressures were at least twice as great as the nominal pressures (total weight divided by block area). The maximum load recorded on one block was 3,590 kPa (521 psi), but the first readings of the pressure wafers were two hours after docking. In two out of three cases the highest load recorded during the docking was borne by the foremost block of the stern blocks. He observed that the sternmost blocks deflected a great deal as they were first loaded during docking and never did fully carry their share of the load thereafter.

Collectively, these studies indicate a general understanding of the approximate average level of FSPL of the common drydocking timbers, and show that docking loads probably have not, in the past, generally exceeded these levels. However, with the possible exception of the two studies cited in (4), it is clear there is no previously available comprehensive data on compressive timber strength that can be drawn on to develop docking plans that involve more difficult drydocking situations such as long overhangs and sonar domes, or for accurately predicting the compression of the the blocks when loaded.

MATERIALS AND METHODS

Returning to the present study, the following paragraphs discuss the types of wood tested and the testing methods. Two types of wood were tested, oak and Douglas fir. Both of these woods are typically used in Navy docking blocks. As shown in Figure 2, oak is used for the body of the block and Douglas fir is used for the soft cap at the top of the block.

The test timbers were selected from several Navy dry docks to provide samples typical of the wood species, sizes, and ages. At shipyards, timbers are usually stored outdoors. Likewise, they were stored outdoors at the test site until being moved to the laboratory for testing. A data sheet was prepared for each timber to record information such as an identification code number, dimensions and weight. A grid of 2.5 cm (1 inch) squares was drawn on one end of each timber to aid in examining distortion during and after loading. Finally a reference photo was taken of the gridded end surface and also of the loaded surface to illustrate knots, checks, splits and other characteristics, if any.

The moisture content of timber can

greatly affect its strength properties. Therefore, shortly before testing, a 2.5 cm (1 inch) diameter core was drilled vertically through each timber in the central area of the face to be loaded. The core was wrapped in plastic film and later was cut into 2.5 cm (1 inch) long sections. The moisture content of each section was determined by the oven-dry method. The moisture content data on the sections indicated the gradient within the timber and the average of the sections was used for moisture content. Specific gravity was also determined on two sections from each core as a measure of timber density.

Compression tests were performed on three timber arrangements: individual timbers: groups of timbers arranged in a single layer or in three layers: and on composite block build-ups consisting of several layers of timbers on top of a concrete block. The general compression test procedure was the same for all three arrangements. The following paragraph describes the general procedure. Succeeding paragraphs describe variations for each timber arrangement.

Each timber (or set of timbers) was tested in compression using a 10.7 million Newton (2.4 million pound) compression capacity Baldwin Test Machine. The timber to be tested was centered under the head plate of the test machine such that the load was applied to the wide face perpendicular to the grain, similar to normal drydock loading conditions. Vertical and horizontal linear measurement scales were arranged next to the gridded end of the specimen for visual reference and the machine head was lowered to contact the timber. Then the timber was loaded in compression. Measurements of timber deflection during loading were obtained by two linear variable differential transformers (LVDTs) placed under the loading head of the test machine at two opposite corners of the test timber. At the conclusion of the test, the timbers were returned to storage.

TEST PROCEDURES

Compression Tests on Individual Timbers

One-Stage Compression Tests. The one-stage compression tests on individual timbers were designed to show comparative properties of full-sized oak and Douglas fir timbers, both old and new. Douglas fir was tested only as a 15.2 x 35.6 cm (6 x 14 inch) cross section. Oak was tested as 15.2 x 35.6 cm (6 x 14 inch) and 30.5 x 35.6 cm (12 x 14 inch) cross sections to compare size effects. The length of all individual timbers was 121.9 cm (48 inches).

After applying an initial load of 1,340 N (3 kips), the Baldwin Test Machine head was stopped for a close-up photograph of the end of the timber that showed the grid. Loading was then

applied at a rate of 13,400 N (30 kips) per minute. Load versus deflection data points were recorded at 30 second intervals by a computer to produce a load versus deflection plot on an x-y plotter for each LVDT while loading progressed.

The computer also recorded the load and deflection at each data point for each timber, then computed the FSPL and the MOE.

A second photograph was taken at 1.3 cm (0.5 inch) deflection, usually past the FSPL. Additional photographs were taken after deflections of 2.5 cm (1 inch) and 3.8 cm (1.5 inches). For timbers that were 30.5 cm (12 inches) thick, a photograph was also taken at the 7.6 cm (3 inch) deflection.

After testing all of the individual timbers in this manner, the load versus deflection plots were examined to determine the proportional limit (yield point) for each timber.

Two-Stage Compression Tests. Two-stage compression tests were performed on individual timbers. These timbers were six Douglas fir and six oak, and all measured 15.2 x 35.6 x 61.0 cm (6 x 14 x 24 inches). Initially each specimen was loaded to a point just above the apparent proportional limit (as observed during development of the stress-strain curve). The following day the specimens were loaded to destruction.

Compression Tests on Layered Timbers

A series of compression tests was run on layers of drydocking timbers to compare with results for individual timbers and to observe the effects of compressive loading without the concrete portion of a typical keel block. Five tests were performed on single layers (of three timbers) of new oak, old oak, and new Douglas fir. Compressive tests were also made on three-layer configurations of new Douglas fir and old oak.

Compression Tests on Composite Block Build-ups

To represent the properties of standard docking blocks encountered at Navy shipyards, ten standard Navy composite build-ups were assembled. Five were formed using new timbers and five using old timbers. The Puget Sound Naval Shipyard furnished ten concrete blocks from their operating inventory for this purpose. These were identified as half pier blocks, each consisting of a steel reinforced concrete block measuring 106.7 cm (42 inches) wide by 121.9 cm (48 inches) long and 38.1 cm (15 inches) high. On the bottom of each concrete block were three 15.2 x 35.6 x 121.9 cm (6 x 14 x 48 inch) oak timbers attached by stud bolts and countersunk nuts.

Composite blockbuild-ups consisting of concrete blocks combined with oak and Douglas fir timbers were assembled to a

nominal 145 cm (57 inch) total height, as shown in Figure 5. The total height of wood in each composite block was a nominal 106.7 cm (42 inches).

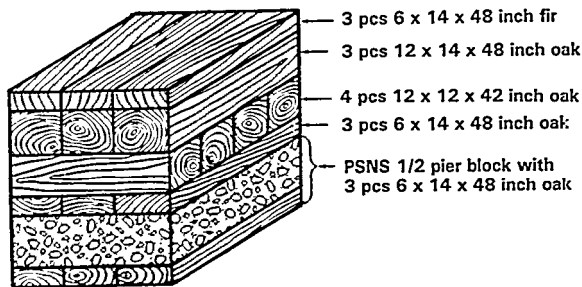


Figure 5
Composite Block Build-Up
As Tested

None of the concrete blocks was new; therefore, the five appearing to be in the best condition were assigned to be used with new timber, and the remaining five were assigned to tests using old timbers. The oak timbers attached to the bottom of the concrete blocks were old in both the new and old test series. Sixteen individual timbers were selected, checked for moisture content, and positioned in layers above the concrete, as shown in Figure 5. The thickness of the timbers within a layer was matched as closely as possible in order to provide uniform loading over the entire area. Thus, the assembled build-up contained two layers of three 15.2 x 35.6 x 121.9 cm (6 x 14 x 48 inch) oak timbers, one layer of four 30.5 x 30.5 x 106.7 cm (12 x 12 x 42 inch) oak timbers, one layer of three 30.5 x 35.6 x 121.9 cm (12 x 14 x 48 inch) oak timbers, and a capping layer of three 15.2 x 35.6 x 121.9 cm (6 x 14 x 48 inch) Douglas fir timbers.

In testing the composite build-up, a 4,480 N (10 kips) pre-load was applied, then loading progressed at a rate of approximately 35,900 N (80 kips) per minute. Load and deflection data points were recorded at 30 second intervals. When the proportional limit was reached, the rate of loading was increased and controlled by deflection at approximately 1.0 cm (0.4 inches) per minute and continued until the total deflection of the composite reached 10.2 cm (4 inches). The load was then slowly released and the build-up was allowed to relax for two minutes, then reloaded to 4,480 N (10 kips) to measure and record "set".

Load versus deflection data for each block build-up were processed by a computer. During the compression testing, a load versus deflection curve was plotted. The computer also listed each data point, selected the proportional limit (calculated as FSPL, psi) and determined the MOE (calculated from deflection as strain, inch per inch)

for the straight line portion of the curve below the proportional limit.

TEST RESULTS

Individual Timber Results

One-Stage Compression Test Results.

Figure 6 shows a series of line drawings traced from photographs of one end of a new 30.5 x 35.6 cm (12 x 14 inch) oak timber during a compressive test. Note that distortion and failure begin in the area of the pith -- marked with a cross in the left center in Figure 6a. Also note the "X" shape of shear in the end-section in Figure 6c. This "X" shape was characteristic of all test specimens. Figure 7 shows the stress-strain curve for the timber photographed in Figure 6.

Table 1 shows the summary of the FSPLs for the one-stage compressive tests perpendicular to the grain on full-size drydocking timbers by species, sizes, and age categories. Table 2 is the summary of MOEs for the same specimens.

Several observations can be made from the above two tables. The first observation is that the average FSPL compressive strength values for new oak and Douglas fir are lower than the bearing test data shown in the *Wood Handbook* for green white oak 4,620 kPa (670 psi) and green Douglas fir (coast), 2,620 kPa (380 psi) (5). This probably at least partly reflects the method of testing (*Wood Handbook* data is derived from testing small clear specimens in contrast to the full-size timbers with various defects and growth characteristics of the present study).

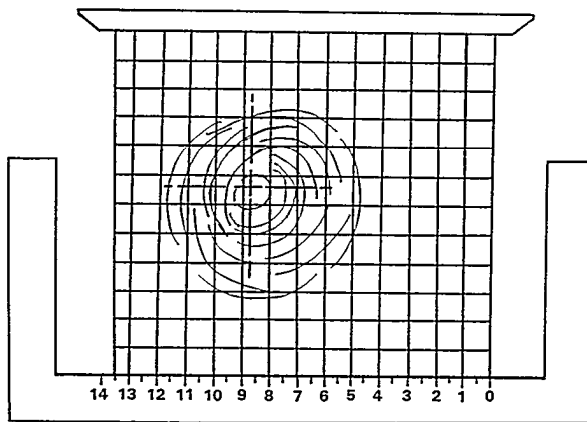
Secondly, it can be observed that the coefficients of variation (COV) for the data are generally in the normal range for clear wood specimens except for the old oak of 30.5 x 35.6 cm (12 x 14 inch) dimensions. Average COV for FSPL perpendicular to the grain in wood is 28 percent [5]. The generally higher COVs of old oak and Douglas fir are likely because some of the old materials, while weathered, had not been used extensively, if at all, and others had been used heavily and contained more checking and perhaps some decay.

Finally, one can observe that the larger dimension 30.5 x 35.6 cm (12 x 14 inch) oak timbers in general are not as strong in compression as the 15.2 x 35.6 cm (6 x 14 inch) oak timbers. This is particularly true for the old timbers.

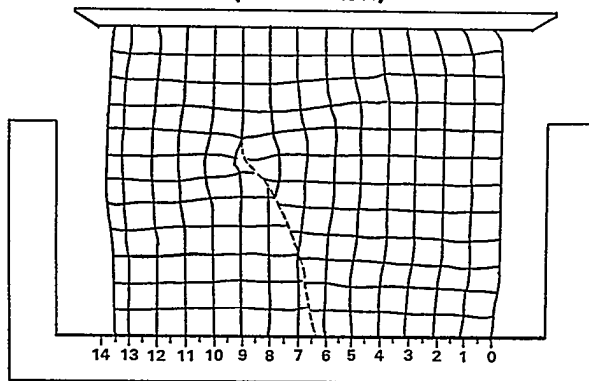
Figure 8, which shows the stress-strain curves for the ten old Douglas fir timbers included in Tables 1 and 2 above, provides a more graphic view of the variability in the old category of timbers.

Comparison with Previous Tests.

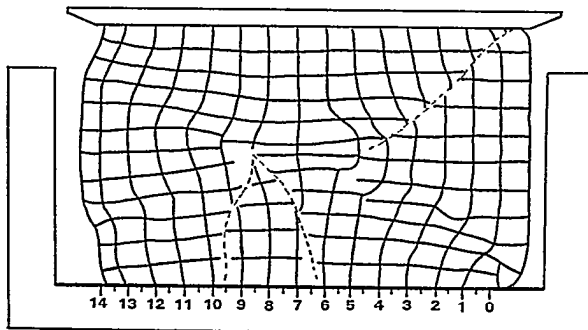
Selected results are available from the Forest Products Laboratory testing of timber keel blocks that were obtained from the Philadelphia Navy Yard (4).



a. Initial Preload
(No Strain)



b. 1 Inch Deflection
(850 psi Stress, 0.08 Inch/Inch Strain)



c. 3 Inch Deflection
(Approx 1230 Psi stress, 0.25
Inch/Inch Strain)

Figure 6
End View of Failure Progression in a
12 x 14 Inch Oak Timber
During Testing

Table 3 presents representative FSPL and MOE values that resulted from tests of individual 35.6 x 35.6 x 48.3 cm (14 x 14 x 19 inch) "minor specimens" of docking block timbers. These specimens were loaded in compression perpendicular to the grain.

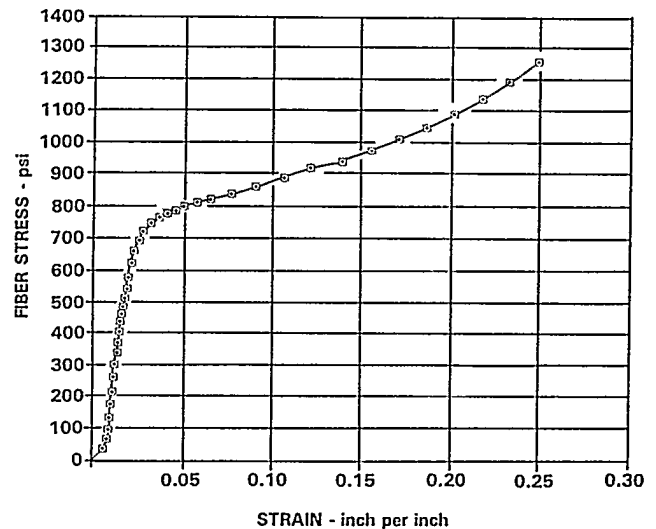


Figure 7
Stress-Strain Curve for Oak Timber,
12 x 14 x 48 inches, Loaded Perpendicular
to the Grain (See Also, Figure 6)

Table 1. Summary of Compression Tests on Individual Timbers, FSPL (psi)

Size		Species			Douglas Fir 6" x 14"
		Oak 6" x 14"	Oak 12" x 14"	Oak Avg.	
New	N	15	15	-	15
	A	35.88	39.86	37.57	26.45
	R	21.5-55.84	31.04-49.79	-	26.3-39.0
	S	8.80	5.4	-	7.17
	COV	24.5%	13.5%	-	27.0%
old	N	15	15	-	10
	A	29.88	21.64	25.76	18.59
	R	15.13-45.83	6.57-56.58	-	4.3-24.0
	S	9.14	13.75	-	6.04
	COV	30.6%	63.5%	-	32.5%
Average of averages		32.9	30.45	31.67	23.31
N = Number of tests R = Range of values COV = Coefficient of variation					
A = Average or Mean S = Standard deviation					

Table 2. Summary of Compression Tests on Individual Timbers, MOE (ksi)

Size		Species			Douglas Fir 6" x 14"
		Oak 6" x 14"	Oak 12" x 14"	Oak Avg.	
New	N	15	15	-	15
	A	567	487	527	328
	R	522-710	389-570	-	263-390
	S	113.75	58.8	-	39.9
	COV	20.1%	12.1%	-	12.2%
old	N	15	15	-	10
	A	561	410	486	405
	R	241-821	257-784	-	279-570
	S	153.6	138.9	-	131.70
	COV	27.4%	33.7%	-	32.5%
Average of averages		564	449	506	359

Two-Stage Compression Test Results.
The results of the two-stage compression tests on six new timbers of each species are shown in Table 4.

The FSPL and MOE values of the first tests in Table 4 are similar to results

for new timbers shown in Tables 1 and 2. The second loading resulted in higher FSPLs and much lower MOEs. This suggests the significantly different keel block performance that may occur if blocks are composed of timbers that contain new timbers along with those that have been stressed beyond the proportional limit. The effect of a series of such loadings, each above the proportional limit, was not studied in this project.

Pooled Compressive Strength Data. Two other experiments on compressive strength of individual full size drydock timbers were carried out for other purposes. These additional compressive strength data were added to the data from Tables 1 and 2 to increase the sample size. Table 5 presents the pooled data for old and new timbers of both species, regardless of cross section dimension.

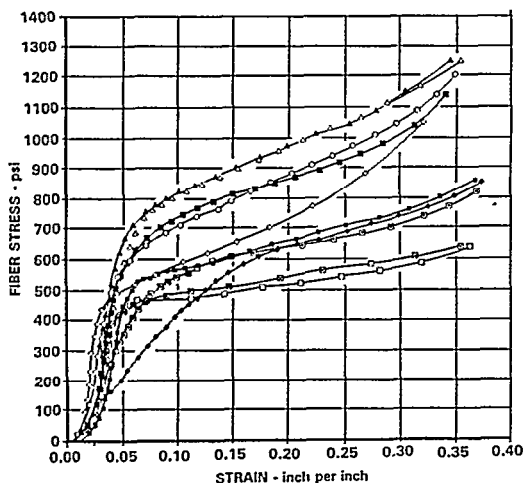


Figure 8
Stress-Strain curves for Douglas Fir (Old), 6 x 14 x 48 inches, Loaded Perpendicular to the Grain

Table 3. Test Data From Philadelphia Navy Yard Oak Timbers

Block Set	FSPL (PSI)	MOE (PSI)
1	298	37,725
2	336	40,535
3	395	47,795
4	301	34,790
5	299	39,475
Average	326	40,064
Range	298-395	34,790-47,795

The data in Table 5 shows the range in values that can be expected from randomly selected timbers in Navy shipyards. It is apparent that there is

Table 4. Two-Stage Compressive Tests on New oak and Douglas Fir Timbers

FSPL (psi)	Oak		Douglas Fir	
	1st Loading*	2nd Loading**	1st Loading*	2nd Loading**
N	6	6	6	6
A	596	689	328	444
R	490-673	485-895	253-421	315-461
S	64.1	144.9	56.5	7.2
MOE (ksi)				
N	6	6	6	6
A	35.48	19.86	26.67	8.05
R	10.6-47.9	12.93-26.80	13.46-35.58	5.85-10.4
S	9.87	5.00	7.83	1.64

* Each specimen loaded to slightly above proportional limit and then pressure released and specimen removed from testing machine for 24 hours.
** Specimens re-loaded to destruction.
N = Number of tests A = Average or mean
R = Range of values S = Standard deviation

not a large difference between FSPL for old and new timbers, but there is a significant difference in MOEs between the old and new. This indicates that the stiffness of individual timbers and, therefore, entire keel block assemblies, may vary substantially in service and fail to uniformly distribute the load of the ship.

Layered Timber Results

The results for the layered timber strength in general were similar to strength values of individual timbers of the same species and age. There was no obvious enhancement of collective strength from forming layers. It was anticipated that as the number of timbers in the assembly increased, the variation of strength properties between test assemblies would decrease. This was not the case with these data, which may have been due to a limited number of tests. These tests did suggest that there is no assurance that the performance of a combination of timbers is any more predictable than for individual timbers.

Table 5. Pooled Data for compressive Tests on Individual Timbers

Species	Age	No. of Specimens	FSPL (psi)		MOE (ksi)	
			Ave.	Range	Ave.	Range
Oak	Old	30	486	241-821	11.4	6.6-56.7
Oak	New	36	539	322-710	37.2	19.6-49.8
D. fir	Old	10	405	279-570	18.6	4.3-24.0
D. fir	New	39	367	258-663	26.8	11.4-38.6

Composite Block Build-Up Results

Composite Block Build-Up Compression Test Results. Results of the tests of the ten composite block build-ups are shown in Table 6. Given that the blocks are comprised of a combination of Douglas fir and oak and that all blocks have an attached layer of old oak, the FSPL and MOE results appear consistent with the results of previous tests on individual timbers and layers of timbers. That is, the FSPL and MOE values of the blocks are

intermediate between values determined for oak and Douglas fir that were determined separately for old and new timbers (see Tables 1 and 2). Also, as noted above, the difference between FSPL for old and new timbers is not great. Individual timbers and blocks made entirely of old timbers are lower in strength on average, but strengths of individual timbers, and in this case blocks, may overlap -- some old blocks are stronger than some new blocks.

The most notable feature of the data in Table 6 is the difference between MOE for old and new blocks. The average MOE of the old blocks is less than half that of the new blocks, and the lowest MOE of the new blocks is almost one-third higher than the highest of the old blocks. The keel block compressive test data are less variable within each group than the data for individual timbers. The coefficients of variation for the tests in general are less for the blocks than for the sets of individual timbers (see Tables 1 and 2) as might be expected from the number of individual timbers included in each block.

Table 6. Summary of Compressive Tests on Composite Block Build-Ups

New Oak Blocks, New Douglas Fir Capping									
	Average					Range	std. Dev.	COV(%)	
FSPL (psi)	530	387	410	390	518	499	387-530	73.97	16
MOE (ksi)	36.41	42.54	36.86	38.97	29.8	36.92	29.8-42.5	4.66	13
old Oak Blocks, Old Douglas Fir Capping									
	Average					Range	Std. Dev.	COV(%)	
FSPL (psi)	304	383	356	400	411	371	304-411	42.72	12
MOE (ksi)	16.59	20.18	19.64	12.58	12.95	16.39	12.6-20.2	3.58	22

Comparison with Previous Tests.
Naval Ships Technical Manual Docking Instruction (NSTM 997) (10) contains a section on "Stress-Strain Characteristics of the Dock Blocks." That section cites deflection data under compressive loads for eight blocks from the Norfolk Naval Shipyard as determined by the David Taylor Model Basin (now David Taylor Research Center, DTRC). Based on that data, Table 7 was constructed.

Although the height of the wood in the present study is 106.7 cm (42 inches) (see Figure 5), the cross section of 106.7 x 121.9 cm (42 x 48 inches) is the same as that of the DTRC block. Therefore, for purposes of comparison, Tables 8 and 9 were calculated for the ten medium blocks tested in this study. Wood height and load were assumed to be the same as for the DTRC tests: 85.1 cm (33.5 inches) wood height and 3,450 kPa (500 psi) load the deflection for each block at the 3,450 kPa (500 psi) load was determined from stress-strain curves for each block. Table 8 contains data on new

timber blocks and Table 9 contains data on old timber blocks.

The configurations of all the blocks were not the same. At least three of the DTRC blocks had "hard caps," assumed to be oak, and four had "soft caps," which were assumed to be Douglas fir, the same as on all ten of the blocks tested in this study. The averages and ranges of deflections and the "apparent" MOEs for the three tables are shown together in Table 10.

The average test results for the DTRC blocks fall between the averages of the old and the new blocks tested in this study, but are closer to the old block values.

The difference in performance under load between the old and new blocks is evident in Figure 9 which presents the stress-strain curves for all ten of the blocks tested in this work. The lower five curves with less slope are the old blocks. These curves show the higher MOEs of new timbers and the greater variability of the old timbers. They also show that the old timbers can carry loads almost as high as new timbers, but

for the same load, deflections are over twice as great.

Discussion of Wood Strength Variations

It is apparent from the data presented above that the Compressive strengths of individual timbers and composite block build-ups are variable. To one unfamiliar with wood, but used to working with concrete and steel, such variations in wood strength may seem surprisingly large. For example, in Table 5, the FSPL for oak varies from 1,660 to 5,660 kPa (241 to 821 psi). This strength variation is far outside that of any single type of steel or concrete. To better understand these wood strength variations, the following paragraphs describe six major causal factors. These factors include moisture content; specific gravity; botanical and commercial classifications; defects: timber cross section proportion; overloading timbers in service; and

Table 7. Tests on DTRC Composite Build-Ups as Reported in NSTM 977

CAP TYPE	NOT REPORTED	HARD CAP	HARD CAP	HARD CAP	SOFT CAP	SOFT CAP	SOFT CAP	SOFT CAP
CAP HEIGHT, IN.	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
TOTAL WOOD HEIGHT, IN.	33	33.5	33.5	33.5	33.5	33.5	33.5	33.5
CAP LOAD WIDTH X LENGTH, INCHES	42X48(1)	36 IN SP(2)	36 IN SP(2)	36 IN SP(2)	36 IN SP(2)	36 IN SP(2)	48X42(3)	48X42(3)
APPLIED LOAD, KIPS	1000	1000	1000	1000	1000	1000	1000	1000
STRESS, PSI (4)	496	496	496	496	496	496	496	496
BLOCK COMPRESSION, INCHES	1.32	0.67	1.11	1.28	1.49	1.74	1.01	1.12
APPARENT MODULUS OF ELASTICITY (5)	12,400	24,300	14,969	12,981	11,152	9,549	16,451	14,836

- (1) DESCRIPTION OF THE TEST DID NOT INDICATE THAT LOAD WAS APPLIED OTHER THAN OVER THE ENTIRE 42 X 48 INCH AREA.
 (2) LOAD WAS APPLIED THROUGH A 36 INCH WIDE PLATE BY 42 INCHES.
 (3) LOAD WAS APPLIED OVER ENTIRE 42 X 48 INCH AREA.
 (4) APPLIED LOAD DIVIDED BY 42 X 48 INCHES (2016 SQ. INCHES)
 (5) APPARENT MODULUS OF ELASTICITY (AMOE) CALCULATED FROM STRESS DIVIDED BY STRAIN ASSUMING A STRAIGHT LINE BETWEEN 0 AND 496 PS ALTHOUGH THE FIBER STRESS AT PROPORTIONAL LIMIT (FSPL) OF SOME TIMBERS MAY HAVE BEEN EXCEEDED.
 (6) WOOD IN COMPOSITE BLOCKS WAS ASSUMED TO BE WHITE OAK EXCEPT FOR CAP: -OAK, SOFT=DOUGLAS FIR. AGE OF WOOD NOT INDICATED.

Table 8. Compression Tests on Composite Block Build-Ups, New Wood

FIVE COMPOSITE BLOCKS COMPOSED OF NEW WOOD (1)					
CAP TYPE (2)	SOFT	SOFT	SOFT	SOFT	SOFT
CAP HEIGHT, INCHES	6	6	6	6	6
TOTAL WOOD HEIGHT, INCHES (3)	33.5	33.5	33.5	33.5	33.5
CAP LOAD WIDTH X LENGTH, INCHES	42 x 48(4)	42 x 48(4)	42 x 48(4)	42 x 48(4)	42 x 48(4)
APPLIED LOAD, KIPS (5)	1008 KIPS	1008 KIPS	1008 KIPS	1008 KIPS	1008 KIPS
STRESS, PSI (6)	500	500	500	500	500
BLOCK COMPRESSION, INCHES (7)	0.61	0.61	0.66	0.62	0.73
APPARENT MODULUS OF ELASTICITY (8)	27,682	27,689	25,557	26,855	22,995

- (1) THE TIMBERS IN THE BUILD-UP BELOW THE CAP WERE NEW OAK EXCEPT THE 6 X 14 X 48 INCH OAK ON BOTTOM OF CONCRETE WERE NOT NEW.
 (2) SOFT CAPS WERE NEW DOUGLAS FIR.
 (3) WHEN TESTED, NOMINAL WOOD HEIGHT WAS 42 INCHES: FOR COMPARISON WITH CH-997 TESTS, HEIGHT WAS CALCULATED AS IF 33.5 INCHES FOR BLOCK COMPRESSION.
 (4) THE ACTUAL DIMENSIONS OF EACH BUILD-UP WERE USED DURING TESTING; LOAD WAS APPLIED OVER ENTIRE AREA.
 (5) APPLIED LOAD VARIED ACCORDING TO ACTUAL LOADED AREA OF EACH COMPOSITE BUILD-UP.
 (6) STRESS CALCULATED FROM ACTUAL LOADED AREA AND APPLIED LOAD.
 (7) CALCULATED FROM THE APPARENT MODULUS OF ELASTICITY FOR EACH BLOCK AS IF WOOD HEIGHT WERE 33.5 INCHES.
 (8) CALCULATED AS STRAIGHT LINE BETWEEN 0 AND 500 PSI.

Table 9. Compression Tests on Composite Block Build-Ups, Old Wood

FIVE COMPOSITE BLOCKS COMPOSED OF NEW WOOD (1)					
CAP TYPE (2)	SOFT	SOFT	SOFT	SOFT	SOFT
CAP HEIGHT, INCHES	6	6	6	6	6
TOTAL WOOD HEIGHT, INCHES (3)	33.5	33.5	33.5	33.5	33.5
CAP LOAD WIDTH X LENGTH, INCHES	42 x 48(4)	42 x 48(4)	42 x 48(4)	42 x 48(4)	42 x 48(4)
APPLIED LOAD, KIPS (5)	1008 KIPS	1008 KIPS	1008 KIPS	1008 KIPS	1008 KIPS
STRESS, PSI (6)	500	500	500	500	500
BLOCK COMPRESSION, INCHES (7)	1.42	1.06	1.19	1.6	1.6
APPARENT MODULUS OF ELASTICITY (8)	11,856	15,796	14,073	10,498	10,492

- (1) THE TIMBERS IN THE BUILD-UP BELOW THE CAP WERE NEW OAK EXCEPT THE 6 X 14 X 48 INCH OAK ON BOTTOM OF CONCRETE WERE NOT NEW.
 (2) SOFT CAPS WERE NEW DOUGLAS FIR.
 (3) WHEN TESTED, NOMINAL WOOD HEIGHT WAS 42 INCHES: FOR COMPARISON WITH CH-997 TESTS, HEIGHT WAS CALCULATED AS IF 33.5 INCHES FOR BLOCKS COMPRESSION.
 (4) THE ACTUAL DIMENSIONS OF EACH BUILD-UP WERE USED DURING TESTING; LOAD WAS APPLIED OVER ENTIRE AREA.
 (5) APPLIED LOAD VARIED ACCORDING TO ACTUAL LOADED AREA OF EACH COMPOSITE BUILD-UP.
 (6) STRESS CALCULATED FROM ACTUAL LOADED AREA AND APPLIED LOAD.
 (7) CALCULATED FROM THE APPARENT MODULUS OF ELASTICITY FOR EACH BLOCK AS IF WOOD HEIGHT WERE 33.5 INCHES.
 (8) CALCULATED AS STRAIGHT LINE BETWEEN 0 AND 500 PSI.

geographic origin.

Moisture Content. The strength of wood increases as the moisture content decreases below the fiber saturation point. The fiber saturation point is the point at which, as wood dries, there is no more moisture in cell cavities and moisture starts to be lost from cell walls, causing shrinkage. The fiber saturation point is usually 24 to 30%, based on the oven dry weight of the wood. Some strength properties will nearly double as wood is dried from the green condition to a "dry" moisture content of 12 percent. In this study, all the timbers tested were above the fiber saturation point, which eliminated this possible variable in comparing the

Table 10. Comparison of Test Data Composite Block Build-Ups

property	DTRC Blocks	New BLOCKS	Old Blocks
Average deflection e496/500 psi (in.)	1.2	0.65	1.37
Range of deflection (in.)	0.67-1.79	0.61-0.73	1.06-1.6
Standard deviation	0.301	0.051	0.1243
Average apparent MOE (psi)	14,642	26,156	12,543
Range of MOE (psi)	9,549 to 24,900	22,995 to 27,689	10,492 to 15,796
Standard deviation	4,668	1,970	2,334

strength of timbers. In drydock use, where timbers are close-packed in storage and re-wetted frequently, most timbers can be considered to be above the fiber saturation point.

Specific Gravity. In general, the strength of wood increases as its specific gravity increases. That is, high density woods are usually stronger than low density woods. Note, however,

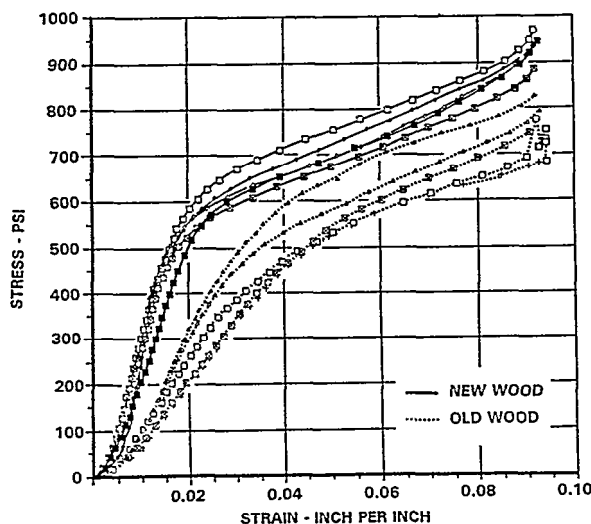


Figure 9
Stress-Strain curves for
Composite Block Build-Ups

that specific gravity alone cannot be used to predict a strength property of an individual timber or species.

Botanical and Commercial Classifications. A factor that may contribute to variations in strength properties of drydocking timbers is the

difference between similar species. Oaks, for example, are divided into two general types -- white oaks and red oaks. The white oaks, being less permeable and thus more durable, are preferred for drydocking timbers. Within each of these divisions are several species with different strength properties. Note in Table 11 that the first three oaks are white oaks and the last three are red oaks.

Table 11. Examples of Variations in Specific Gravity and Strength Among Some Oaks (5)

species	specific Gravity (green)	compression Perpendicular to the grain (psi)
White Oak	0.60	670
Chestnut oak	0.57	530
swamp white oak	0.64	760
No. red oak	0.56	610
So. red oak	0.52	550
Black oak	0.56	710

Defects. Strength properties in the Wood Handbook (5) are based on tests of small, clear, straight-grained specimens. Usually, wood of this quality cannot be obtained in larger pieces, particularly in those sizes used for drydocking timbers. The incidence of knots, splits, sloping grain and decay all may detract from strength. One or more of these defects can account for some reduced strength of the old timbers in the tests of this study.

Cross Section Proportion. In Tables 1 and 2, which compare 15.2 x 35.6 cm and 30.5 x 35.6 cm (6 x 14 inch and 12 x 14 inch) timbers, it can be seen that oaks with the 15.2 x 35.6 cm (6 x 14 inch) cross section generally have higher FPSL and MOE values (with one exception in the MOE of new 30.5 x 35.6 cm (12 x 14 inch) oak timbers). It is suggested that this difference is partially explained by the influence of the height of the specimen with respect to its width. In his work on Poisson's ratio of wood in transverse compression, Bodig (16) observed that the height/width ratio had a strong effect on the apparent Poisson's ratio. The greater the height of the specimen in relation to its width, the greater was the opportunity for the specimen to bulge in the middle section as the load is applied, while friction at the upper and lower surfaces prevents its lateral

displacement. Specimens with a greater height/width ratio had higher Poisson's ratios and lower FSPL and MOE values.

Further, the larger 30.5 x 35.6 cm (12 x 14 inch) timbers all have pith within the cross section which contains wood that is not as strong as in outer portions. Note in Figure 6 that the failure in the timber begins in the pith area which was typical for individual timbers in this study.

Overloading in Service. The variability of old timbers, individually or in a composite build-up, is usually greater than for new timbers, and the strength of the old timbers is usually less. Some of this variability in a group of timbers, particularly evident in the low MOE values, is probably attributable to previous instances of excessive loading that exceeded the timbers' FSPL. We suggest that as timbers are cross-stacked in layers, adjacent timbers may differ significantly in MOE. Therefore, no timber carries the same unit stress along its full length. Consequently, when load is applied to the entire surface of a layer of three or four timbers, the greatest load at the intersected bearing area will be absorbed by the timbers with the highest MOE and perhaps exceed their proportional limit. If such high MOE timbers are relocated, other areas along their length may be similarly affected until their overall load carrying capacity is reduced.

Table 4 demonstrates how strong the effect of exceeding the proportional limit during loading can be on the subsequent stiffness of the timbers. This effect is also suggested in the reference on investigation of drydocking of three aircraft carriers (15), where the highly stressed sternmost keel blocks did not share the load with blocks just forward of them after docking was complete.

Geographic Origin. A minor factor for some commercially important and widely distributed woods is their geographic origin. For most species this is not a consideration and is not a factor in acquiring wood for structural purposes. But Douglas fir is an exception; its strength properties differ for wood originating in "coast" and "interior" regions of the U.S. For example, the average strength in compression perpendicular to the grain for coast Douglas fir is 2,620 kPa (380 psi); for interior Douglas fir it is 2,900 kPa (420 psi) [5]. The cause of this type of strength variation may be associated with genetic differences between the woods.

CONCLUSIONS

Briefly, we have drawn the conclusions that follow.

1. Transverse compressive strengths of oak and Douglas fir timbers are variable and this must be considered along with the average strength for drydocking uses.
2. Old (previously used) timbers are more variable in compressive strength properties than new timbers both in FSPL and MOE, but are not necessarily weaker in FSPL. This suggests that although the average unit stress on keel blocks may have been within the recommended limits, stresses on individual timbers may have exceeded FSPL and produced a lowering of MOE.
3. Average FSPL of timbers tested in this study, although slightly lower, compare favorably with published strength values in the *Wood Handbook* (5).
4. The average MOEs of old timbers and other timbers compressed beyond their proportional limits are much lower than MOEs of new timbers, but their load carrying capacity is not damaged.
5. Variations between composite block build-ups are less than between individual timbers.
6. The compressive strength properties of the blocks tested by DTRC were comparable to the blocks made of old timbers tested in this study, which suggests the data presented here is a fair representation of the keel block population.
7. The compressive strength properties of the individual timbers from the Philadelphia Navy Yard (4) were comparable to the strength properties of the individual timbers of the present study, although the Philadelphia timbers have a somewhat lower FSPL (perhaps because of their higher cross section) and a higher MOE than did the timbers of the present study.

IMPLICATIONS FOR NAVY DRYDOCKING

What follows are the implications of this study for Navy drydocking.

1. The variability in compressive strengths of existing keel blocks requires conservative assumptions in anticipating average keel block loads.
2. To avoid "hard spots," which result in localized excessive loads, it is necessary to provide sufficient height of wood build-up in keel blocks. The theoretical calculations of Table 12 show the effect of varying wood height on the resulting average keel block load.
3. Because the strength properties of oak and Douglas fir overlap, the use of Douglas fir as a soft cap should be re-examined. Better load distribution could be obtained with a layer of a lower MOE wood.

Table 12. Theoretical Keel Block Loads for Equal Deflection and Two Heights of Wood

Total Deflection (inches)	18-inch Wood Height				36-inch Wood Height			
	Unit Strain (in./in.)	MOE* (psi)	Load (psi)		Unit Strain (in./in.)	MOE* (psi)	Load (psi)	
0.5	0.028	12,000	336		0.014	12,000	168	
0.5	0.028	20,000	560		0.014	20,000	280	
0.5	0.028	40,000	1120		0.014	40,000	560	

*Assumed average MOE for timbers in the keel block.

- Replacing 30.5 x 35.6 cm (12 x 14 inch) timbers with 15.2 x 35.6 cm (6 x 14 inch) timbers would gradually improve the average strength of keel blocks. (However, high quality 30.5 x 35.6 cm (12 x 14 inch) timbers under the keel would improve lateral distribution of the load from the keel.)
- Except for very obvious physical damage or decay, the strength of keel block timbers cannot be determined by visual observation. A nondestructive device for testing timber stiffness could help eliminate weak timbers and improve predictability of keel block performance if timbers of comparable stiffness were placed in the same layer.
- When old timbers are replaced, new timbers should be placed in blocks as a complete layer and preferably at the same level in each keel block so that individual timbers are protected from excessive loads and keel blocks gradually assume more uniformity over time.

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Life Cycle Design for Marine Vehicles

IXA-2

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ABSTRACT

The design process for a marine vehicle is essentially an iterative process where different characteristics and parameters are modified until the optimum compromise is achieved. However, in day to day running of these vehicles we notice that they don't perform as well as we expect. This is an indication that some of the parameters have been ignored during the design process. In this paper it is suggested that when designing a ship, a life cycle analysis should be carried out. Many concepts should be included in the conceptual design, which include: maintainability, maintenance, supportability, reliability, logistics support, safety, and testing. In essence, it has been found that Reliability, Maintainability and Supportability (R/M/S), as design characteristics could have a tremendous impact on the ultimate effectiveness and economic support of a system in the user environment. Further, it has become increasingly evident that R/M/S considerations are not adequately addressed in the design process. If considered at all, these factors are introduced "after-the-fact," which can be a costly experience should changes be required at this stage.

This paper proposes a new approach to design, a life cycle engineering approach, which presents an integrated approach for bringing competitive products and systems into being in such a way as to minimize their deficiencies and life cycle cost. This involves the integration of performance, producibility, reliability, maintainability, manability (human factor), supportability and other "ilities"

into the overall design process. It would bring R/M/S to the front-end of design of a new system or piece of equipment. This paper deals primarily with application of the above to ships, the concepts, however, are general and can be equally applied to other types of complex technical systems.

INTRODUCTION

Ship design is amongst the professions which were dominated by tradition more than other factors. This is not surprising considering the fact that history of ship design goes back many thousands of years and may be one of the reasons for this industry to have been reluctant to accept new concepts. This picture, however, has been changing very rapidly. Changes are taking place as a result of technological advances, especially in computing areas, and furthermore, there is an increasing demand by the ship owners and operators for more availability of ships (associated with higher reliability and lower maintenance) and the governments and other governing bodies for design of safer vehicles.

Changes in the ship design process can be summarized in more usage of digital computers to conduct various tasks involved in the design process. Computer Aided Design and Manufacture are being used very widely in marine vehicle design. Other concepts such as reliability analysis are also being imported from other industries, specially the military sector, where high reliability of systems is paramount. These new techniques are welcomed by all concerned, as they help the de-

signers and manufacturers to perform their tasks more efficiently, and in this respect the industry seems to have responded well and be on the natural way to progress. However, compared to other industries, with similarities to ship design (e.g automobile design, aircraft design) it would appear that we are lagging behind. This may partly due to the risks involved in a total or partial failure of a ship and partly due to the initial capital investment required to introduce an extra amount of work in the ship design process.

To highlight some shortcomings of the classical approach to ship design let us consider some questions to which this approach cannot provide satisfactory answers.

- * At the beginning of operation a marine vehicle meets its performance and other legal requirements; but will it continue to perform in a reliable and safe manner for the period required?
- * If it should fail, is it maintainable and can it be supported?
- * Can the vehicle be operated and maintained in a cost effective manner?

When dealing with a ship's operational requirements, there are many questions that must be considered. In most cases the answers to the above questions provided by ship designers or manufacturers are very basic and limited. The reason for this is the dearth of information which is the result of inadequate front-end planning and lack of an integrated approach to ship design. Often the problems associated with poor effectiveness and the high costs of operation and maintenance support are the consequences of decisions made in the early stage of design.

In essence, it has been found (specially in the aerospace industry) that engineering disciplines like reliability, maintainability and supportability, as design disciplines, have a tremendous impact on the ultimate effectiveness and economic support of a system in the user environment. Further, it has be-

come increasingly evident that R/M/S considerations are not adequately addressed in the design process. If considered at all, they are introduced at such a late stage ("after-the-fact"), which can be a costly experience should changes be required.

Thus, this paper proposes application of a Life Cycle Analysis Approach to ship design, the main objective of which is to bring a competitive marine vehicle into being in a way which minimizes their operational deficiencies and life cycle cost. This involves the integration of: performance, producibility, reliability, maintainability, manability, supportability and other related disciplines into the overall design process. This approach brings R/M/S to the front-end of design process of a new marine vehicle.

The approach proposed here alters the traditional view of design and supplements it with additional tasks, as a result of which the available information for decision making process during the design considerably increases. The gained knowledge will also reduce the shortcomings of classical approach to ship design already highlighted.

LIFE CYCLE OF A SYSTEM

Fundamental to any engineering design practice is an understanding of the cycle which end product goes through during its life. The life cycle of a system or product begins with the initial identification of the needs and requirements and extends through planning, research, design, production, evaluation, operation, support, maintenance and its ultimate phaseout (see Fig. 1). The above phases are common to all engineering systems but certainly the scope and activities performed in each of them would depend on each individual system considered.

The classical approach to engineering looks at each of these phases as separate entities. Designers design the system, production team produce it, operators use it, maintenance engineers perform all repairs and so forth, without adequate interaction and feed-

back between these groups and activities. Indeed some of the operational problems associated with ships are believed to stem from the lack of coordination, contact and feedback between the above mentioned groups.

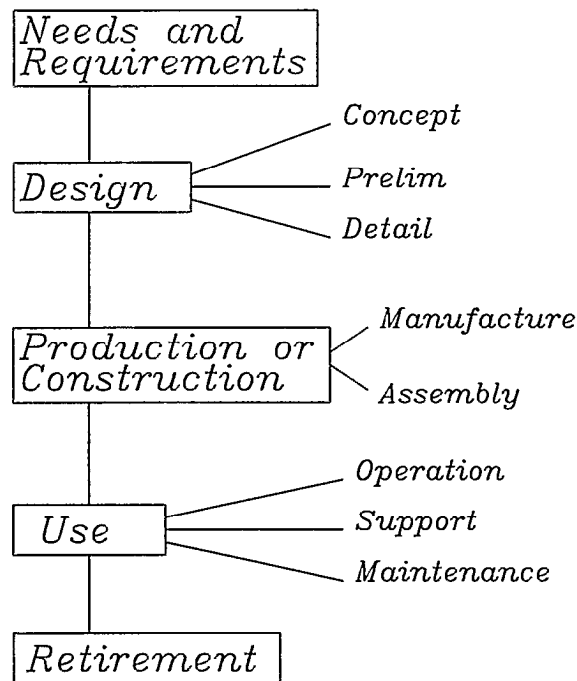


Fig. 1 Life Cycle

Following list contains some of the tasks and activities performed at various phases of Life Cycle:

Design:

- * Management
- * Planning
- * Research
- * Engineering design
- * Documentation
- * Software
- * Scale modelling
- * Test & evaluation

Production:

- * Management
- * Operational analysis
- * Manufacturing

- * Assembling & construction
- * Quality assurance
- * Initial logistic support
- * Testing
- * Delivery

Use:

- * Management
- * Operation
- * Distribution
- * Maintenance
- * Inventory (spares etc.)
- * Training
- * Technical data
- * Modification

Retirement:

- * Disposal of non-repairable elements
- * Phase-out
- * Documentation

It is suggested here that a classical design team which consists of experts for various aspects of the design stage, should be transformed into an Integrated Design Team (ITD) which will incorporate other technical disciplines related to the vehicle's life cycle (e.g. production team, operators etc.).

The concept of life cycle design proposes that in designing a complex multi-element system (such as a ship or an aircraft) a better design, from the point of view of minimum Life Cycle Cost (LCC), can only be achieved by considering all cost categories related to the complete life cycle at the conceptual stage of design. The emphasis in more detailed analysis at an early stage is primarily due to the fact that at this stage commitments are minimal and changes can be incorporated at ease and low cost [1] (see Fig. 2). This technique has already proved to be very successful in automobile industry [2].

One of the current requirements of the Department of Defence (USA) is that LCC should be used as one of the main acceptance criteria for all military equipment. It is expected that the U.K. and other European countries will follow the U.S. example in the

near future.

In order to apply the life cycle cost analysis to ship design the new concepts should be introduced into the existing design spiral.

CURRENT PRACTICE: DESIGN FOR FUNCTION ABILITY

The main objective of design for function ability is to create a product which will perform a set of desired functions according to specified requirements. In order to relatively achieve this, designers select all the necessary components and put them into the proper relationship that size, weight, volume, shape, accuracy, capacity, speed of performance, power output and all other technical and physical characteristics that the product must possess during its operational life are relatively satisfied. The ability of the system to perform required functions under specified conditions is defined as function ability [2].

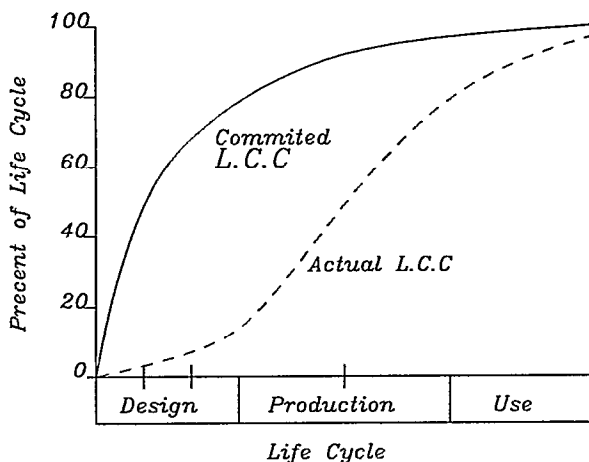


Fig. 2 Actions Affecting Life Cycle Cost

In essence design for function ability implies that at commissioning time a product should satisfy the needs and requirements mentioned above including safety and other legal aspects. Looking at ship design as is practiced today, most of the computing facilities are used only to speed things up and satisfy function ability. Some computer packages are now available in the market which do perform tasks which can be considered as Com-

puter Aided Design (CAD) in the true sense (e.g. designing more refined hull forms using numerical solutions to the hydrodynamic equations). One major problem with most of these packages is that they have been developed very much in isolation and data transfer and integration of these within a larger CAD system is virtually impossible rendering these packages, although very useful in a theoretical sense, somewhat useless. Thus when developing such computer based packages, one should take into account the existing CAD systems and the problem of data transfer in and out of the new tools being developed. Due to economic constraints in most cases the conceptual design stage is a short and speedy process. Therefore a large number of questions remain unanswered and decisions made are based on incomplete information, with the designers confidence mainly based on the previous designs which bear similarities to the design in hand.

A difficult part in any engineering design is the fact that as it proceeds, various options are eliminated. One way of dealing with this problem is to run several different options in parallel ($D_i, i = 1, n$, in figure 3). This approach would have been ambitious and probably impractical a decade ago, however, it is now possible to conduct this exercise using powerful computing facilities with vast storage area at a reasonably acceptable cost. Hence the idea of a design spiral still holds, but instead of one spiral we would have a number of them running in parallel and based on various options. This would allow decisions to be made based on comparison between different design options, at a much later stage of design where more information is available. But this is still classical design, i.e. design for function ability which does not provide sufficient information regarding the operational efficiency and overall life cycle cost effectiveness of the vehicle under consideration.

DESIGN FOR LIFE

The design process described above is a succession of events and iterations through the design spiral or optimization in parallel,

both of which are not satisfactory because they ignore the important life cycle concepts. Some of them are described below. Detailed quantitative descriptions of these are given in references [2] and [3].

Reliability

The characteristic of design and construction concerned with the successful operation of the ship throughout its operational life are known as the reliability characteristics. Reliability is often expressed as the probability of success and is measured in terms of MTBF (mean time between failures), failure rate, percentage life etc. The main objective of reliability based design is to maximize operational success. As a result, failures are minimized.

Maintainability

The characteristic of the design and construction that is concerned with the ease, economy, safety and accuracy in the performance of maintenance actions is known as maintainability. The objective of maintainability is to minimize maintenance times, by providing proper accessibility, diagnostic facilities, and standardization.

Supportability

This characteristic of the design is related to requirements needed for the performance of the maintenance tasks, like: equipment, tools, facilities, personnel, software and supply. The main objective of the supportability analysis is to identify and minimize the support resources required during the life cycle.

Manability (human factor)

The characteristics of the design that is directed toward the optimum human-machine interface (i.e. ensuring the compatibility between the physical system and functional design features and the "human element" in the operation, maintenance and support of the system or equipment) is "manability". Human factor considerations try to ease the use

of equipment and results in reducing personnel skill levels, minimizing training requirements, and minimizing potential personnel error rates.

Producibility

The characteristic of the design that allows for the effective and efficient production of one or a multiple quantity of items of a given configuration is producibility. The objective is to minimize resource requirements (i.e. human resources, materials, facilities, energy) during the production process.

Logistics Support

The characteristic of the design directed towards ensuring that the ship can ultimately be supported effectively and efficiently throughout its planned life cycle is logistic support. An objective is to consider both the internal characteristics of equipment design (reliability, maintainability, human factors) and the design of logistic support capability of the organizations concerned.

Economic Acceptability

The characteristic of the design and production which is directed toward maximizing the benefits and cost effectiveness of the overall vessel configuration is economic acceptability. An objective is to base design decisions on life cycle cost in addition to acquisition cost (or purchase price).

Social Acceptability

The characteristic of design which is directed towards ensuring that the vessel can become an acceptable part of the social system. Here the objective is to seek minimum pollution, ease of disposal, minimum safety risk, high transportability etc.

INTEGRATED FRONT-END DESIGN

In order to encompass all aspects of the life cycle of a ship at the design stage, it is nec-

essary to perform a series of analyses regarding all concepts of design mentioned in the previous sections and integrate them within the design process as shown in figure 3.

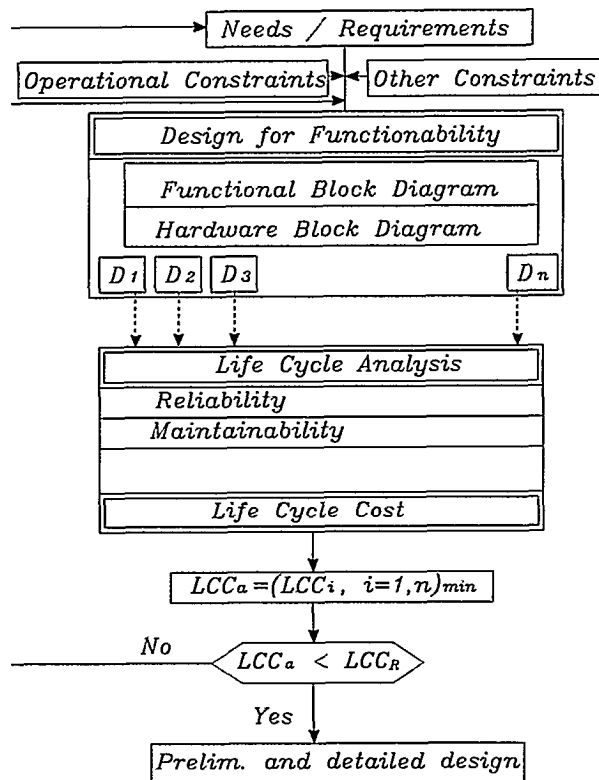


Fig. 3 Life Cycle Design

LCC_a and LCC_R in figure 3, refer to the achieved and required life cycle costs.

Operational concept

The operational concept is a description, qualitative and quantitative, which gives the designers the boundaries for the system. The vessel is defined and constrained by these criteria, which are usually determined through the requirements of the customer or market demand. In many cases such a design description is performance or function orientated, whereas information related to the operating conditions to which the vessel will be subjected are not included. This information is important for the assessment of the design. Environmental conditions which the machine is subjected to, operating profile and stresses

(humidity, shock, vibration, temperature cycles) and transportation profiles for the ship exposed to frequent movement during its operational life are, criteria which influence the decisions of the designers.

Functional Block Diagram

The main aim of producing a functional block diagram is to establish a breakdown structure related to the function which the vessel is expected to perform, applying the top-down approach. Thus at this stage the vessel exists as a collection of elementary functions which have to be performed for the satisfactory operation of the vessel.

Hardware Block Diagram

The basis for the hardware block diagram activity is the establishment of a hardware breakdown structure of a ship to be designed. This is based on top-down approach related to the hardware. Therefore, defining the structure in this way the ship exists as a collection of assembled units grouped in logically, separated entities. For each further breakdown, the vessel is partitioned into its basic building blocks that provide the lowest level of the breakdown structure. The depth for the structure is based on the need that is required for subsequent analysis steps. The hardware block diagram is closest representation of the ship at that moment.

Life Cycle Analysis

At this point of conceptual design the ship under consideration should be analyzed from the points of view of the new topics described in the section "Design For Life" above. Only a few of them will be discussed here.

Reliability Analysis. Part of the integration of the design concept is that reliability should be built into the system and not used for measuring performance after the system has been built.

In making reliability block diagrams of a ship, the individual components, their appli-

cations, stresses and tolerances are evaluated against the operating modes and functions of the vessel as a whole. Thus, the design goal in attaining high reliability rests on the ability to select and apply those components and materials that meet the requirements.

The predictive analysis called the Failure Modes and Effects Analysis (FMEA) [3] involves an inductive approach which starts from failure and goes to effects on the system. It identifies potential system failures, causes of failures, and special maintenance characteristics that have to be observed. The main aim of FMEA is to identify the weaknesses of design, in terms of high failure rate items [4].

Maintainability Analysis. Failure characteristics defined by FMEA require maintenance actions to restore the system to its satisfactory condition and these are defined only to the extent that a task has to be carried out. There is no definition or procedure as to how to carry out that task. The activity which accounts for maintenance actions which have to be performed and the necessary resources identified is called the maintainability analysis [5].

Maintainability characteristics are direct results of reliability and design of the vessel. The main aim is to design a ship in such way that it can be maintained without excessive investments of time, personnel, materials, facilities and support and test equipment. Maintainability can only seek to minimize the resource involved in the performing maintenance actions, whereas their elimination can only be done through design.

Thus maintenance actions are identified through maintainability analysis and they are assigned as a value to the design in a similar way as reliability does with reliability values.

Safety Analysis. When discussing design for functionability it was mentioned that apart from functional requirements and needs, a new design must also satisfy the legal aspects and meet the rules as laid down by various regulatory bodies. A large proportion of

these regulations deal specifically with safety aspects of the design, specially when designing a new vehicle intended to carry passengers. Numerous disasters in the recent past kept reminding us how important safety considerations are and also indicated the inadequacy of the existing regulations. In some recent publications [6, 7] it has been suggested that designers should not be satisfied in designing only to the regulations. It is their professional duty to look at the safety aspects more closely and exploit different avenues and, if necessary, review the whole design process to ensure that safety of life and property is not put at undue risk. The authors support this positive attitude and feel that researchers must provide guidelines as to how these improvements should be made.

In this paper some concepts have been covered as a result of which a more reliable vehicle can be produced. This increase in reliability tied with other concepts covered here will improve the safety standards for marine vehicles.

Cost Analysis. Lately, the interest in cost after the purchase has grown tremendously among users. The designers and producers have good knowledge of the fixed cost of investment and expense of development and manufacture, but the operating and support costs must be forecasted. A way to determine these costs is through the application of a life cycle cost analysis.

Life cycle costs include the costs associated with all activities pertaining to research and development, design, test and evaluation, production, distribution, operation, maintenance and support and disposal costs.

Each component has a fixed cost that it contributes to the entire system giving a total life cycle cost.

Although it is difficult to state how certain costs will behave, it is possible to relate the factors that influence cost behavior. The most influential factors are: components reliability; maintenance efforts to restore opera-

tion and its support; unit cost of components; and the environment in which the system operates.

Integration of All Analysis

Designers are continually faced with the problem of choosing among alternative courses of action in designing, producing and operating the vessel. Many factors, some tangible and some intangible, must be considered before a decision is made.

Despite the fact that they have very different natures all these decision-making factors can be correlated to a single factor: life cycle cost. It is necessary to underline that this is not accounting costs (historical costs) which show what has happened under existing conditions. This is the future cost which represents what is expected to happen under an assumed set of conditions. This would answer an important question: What would happen if this was done? Relevant design, reliability, maintainability and supportability information are inputs to a life cycle cost model of the vessel under consideration and its operational environment. This is a projected figure of merit for the current design.

OPTIMIZATION CRITERION: LIFE CYCLE COST

As the reliability analysis determines the reliability of the system, the maintainability analysis quantifies the maintainability figures of the system, and the supportability analysis determines what resources are to be expected to maintain the system, the life cycle cost analysis determines a cost figure in the overall measure of merit based on the design, production/construction, operation, support, maintenance and retirement of the system.

At the end of one round through the design spiral, we get only one set of values. But what happens when design changes or a component has changed with different reliability and different maintenance requirement? The designer must recognize that one round through the spiral gives us only a static

view of the design. Part of the solution to this problem is utilization of life cycle cost which enables us to measure and quantify the changes made at a design stage against a different configuration. The whole decision making process during the design stage rests on the premise that the design can be quantified through a cost. Changes to the system have an overlying decision criteria that encompasses the key design parameters.

The design aims of high performance and reliability, low maintenance, and cost have a mechanism to trade-off each goal against the others. Alternatives in design are evaluated in each of the steps of analysis and are quantified through the life cycle cost analysis.

In any design alternative, varying factors assist the decision making process. For example, one alternative component might perform the same function with a higher unit cost, but has a significantly lower failure rate and demands more highly qualified technicians for maintenance than the alternative. The common denominator through this process is the decision making cost: life cycle cost.

Effectiveness Factors

In order to quantify the effectiveness factors of the system under consideration it is necessary to consider the following:

- * System performance/technical parameters: capacity, delivery rate, range, volume, speed, weight and similar;
- * System operational and support parameters: availability, capability, operational readiness, reliability, maintainability, and so on;
- * System life cycle cost: research cost, design cost, production cost, operation and maintenance cost, retirement and disposal cost.

Thus, figures of merit, FOM, which quantify the effectiveness of the system should establish a relationship between the above men-

tioned categories. Some possible figures of merit are mentioned below:

$$\text{FOM} = \frac{\text{availability}}{\text{life cycle cost}}$$

$$\text{FOM} = \frac{\text{reliability}}{\text{life cycle cost}}$$

$$\text{FOM} = \frac{\text{system capacity}}{\text{operational range}}$$

or other.

The benefit of the effectiveness of FOMs is particularly appropriate in the evaluation of two or more alternatives when decisions involve design and operational parameters. Each design configuration (D_i in figure 3) is evaluated in a consistent manner employing the same criteria for evaluation which cover the whole life cycle horizon of the system under consideration.

CONCLUSION

This paper has examined some new concepts for inclusion at the conceptual stage of design of a marine vehicle in order to minimize some of the deficiencies currently present in ship design practice.

The notion of design for life cycle was discussed, by first looking at the current trends in ship design and looking at some shortcomings there-in.

Reliability, Maintainability, Supportability and some other related concepts and their application to ship design were discussed, in a qualitative manner. A quantitative approach requires much elaboration which is outside the scope of this paper, and has already been carried out in a series of lecture notes in connection with short courses for the industry at the University of Exeter.

Some software has already been developed by commercial firms [6], and work has recently been completed at the Center for Industrial Reliability and Cost Effectiveness at the University of Exeter, to develop an integrated software package for life cycle system

design which can be custom made to be applied to ship design.

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The Eight-Hour Workday: An Unattainable Goal

IXB-1

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ABSTRACT

No industrial operator can be fully productive for an entire shift. Interference with the productive process occurs during the work day that is beyond the operator's control.

Once the industrial engineering analyst has produced a normal time for an operation, the standard is still not complete. The analyst must account for personal, fatigue, and delay (PF&D) time and factor the appropriate allowances into the normal time to produce a true standard time. Allowing for personal needs is usually not enough. Operators experience fatigue due to the stress factors that are abundant in ship repair processes. Delays are incurred when multiple trades must combine their skills to complete one work cycle. These personal, fatigue, and delay factors are steadily increasing, as technological, safety, and environmental needs are discovered, making many processes more complicated. Some other factors that affect the work day are: mustering of personnel for shift changes; preparing turn-over reports for ensuing shifts; attending to administrative requirements; and general work area cleaning.

INTRODUCTION

To accurately account for all of the factors affecting the work day, the industrial engineering analyst must become familiar with the nature of the work, the environment in which it is performed, and all governing regulations. Since it is not unusual for operators to take short-cuts, especially where safety and environmental requirements are concerned, it is important that the analyst develops personal, fatigue, and delay allowances in compliance with existing regulations. In ship repair work, allowances for similar operations may vary widely from one work cycle to

another, depending on conditions and requirements. Welding in a tank, for example, requires considerably greater allowances for working conditions and safety than welding on an open bulkhead. The analyst cannot afford to apply a general factor but must develop an individualized allowance for each operation based on personal observations and experience with the actual conditions. Developing a PF&D allowance is an integral part of determining direct labor charges.

To illustrate the development of PF&D allowances as this paper progresses, a running example will be created using the Department of Defense (DoD) requirements (1). The example will consist of an electrician mounting a 40-pound piece of electrical equipment at waist level in a ship's machinery space.

PERSONAL TIME

Workers must attend to personal needs, such as going to the rest room, getting fresh air, or getting a drink. Allowances for these personal needs are usually defined by company policy or negotiated into a labor-management agreement and do not have to be redefined for each job. For example, the Department of Defense personal time allowances are 9 percent for indoor (shop) work and 14 percent for outdoor (shipboard) work (1).

If the analyst needs to develop personal time allowances, the best approach is through a work-sampling (ratio-delay) study. Company policy regarding personal time should be defined before beginning the study. The items to be observed are primarily trips to the restroom and drinking fountain, getting fresh air, special clothing requirements (for example, 'clean-room' garb) and, where applicable, lunch breaks (1). Criteria to be considered are the distances the worker must travel to use the

facilities and the disruption to the job that the trips cause, such as having to store tools or secure the job before leaving the work site. Items such as rest breaks or changing safety equipment are not normally considered personal time. The results of the study should be reviewed with management and labor before they are applied, as these parties often disagree on this type of allowance.

FATIGUE

The study of fatigue in workers. and the development of allowances to compensate for it, is a point where many analysts disagree when applying PF&D allowances. Every operator works at a slower pace towards the end of the shift than at the beginning (2). This slowing is more apparent in some workers than in others. Fatigue is greater in ship repair than on the typical progressive assembly line, due to the multiple stresses on workers and the less-than-favorable working conditions aboard a ship under repair. Pace rating will not adjust the normal time for this slowing since the change in pace is not consistent. A standard developed by motion-time analysis has the pace rating built in and does not reflect the normal slowing of a worker throughout the work day. Some organizations create standard allowances for fatigue (1). They may be included in a labor-management agreement. Scheduled morning and afternoon rest breaks, normally 5-15 minutes each (2), are a common way to compensate for worker fatigue.

The two stresses that create worker fatigue are mental and physical. Concentration, lighting, temperature, humidity, air quality, color of the work area, and noise are all factors that affect mental stress. Physical stress is caused by working position (sitting, standing, walking, and cramped quarters (1). weight handling, repetitive motions, and disagreeable working conditions (3).

Mental Stress

A worker is more fatigued by work that requires intense concentration than by work that is largely habitual, although monotony from highly repetitive. short-cycle work will also cause fatigue. Glare from a work surface or inadequate lighting (less than 75 foot-candles for normal work or 125 foot-candles for close work (1)) creates worker fatigue. High noise levels can severely tire a worker.

Physical Stress

To account for weight handling, the analyst must consider the amount of weight being handled, the manner in which it is handled, and the percentage of the work cycle that the worker handles the weight. Physical stress is considerably greater when a weight is lifted than if it is simply rolled or slid (1).

Physical stress is also largely affected by the working position. Little stress is felt by a worker who sits during much of the work cycle. A worker who must crawl into a tight spot and work in an unnatural position will experience great stress. Cost overruns can occur when the working position and other fatigue factors are not accurately identified. For example, welding a two-inch thick aluminum joint could cost 4.0 manhours per lineal foot under normal conditions. The same two-inch joint welded under close, cramped conditions could cost 4.0 manhours per lineal foot (4). If the proper PF&D was not applied to account for the difficult working position, this job would most likely be overexpended by 0.8 manhours per lineal foot or 20 percent over the cost bid to the customer. Since welding comprises a large portion of ship work. the cost overrun could be enormous.

Determining the fatigue allowance for mental and physical stress usually requires studying an operation throughout the work day. The actual effect on workers varies between individuals, based on their stature, diet, health, mental state (3), and other factors which the analyst can neither detect nor control.

To develop a reasonable fatigue allowance, the analyst must study the worker's performance over an entire shift. Normally, production increases during the early part of the shift, then falls off during the third hour. After the lunch break, production increases for a short period, then declines for the balance of the shift (3) - As with all studies, the more observations that can be made, the more accurate the study results. Any drop in productivity that cannot be attributed to other causes, such as personal time, poor worker health, or unavoidable delays, should be attributed to fatigue. The time to complete a single task (one work cycle) should be measured repeatedly throughout an entire shift. The difference between the time to produce one work cycle at the beginning of the shift and one work cycle at the end of the shift can be expressed as a

percentage. Any scheduled rest breaks should be subtracted from the total fatigue allowance.

Example:

A piece of equipment weighs 40 pounds and is lifted from the deck to the waist-high mounting location (3.45 percent weight allowance), working from a standing position (2 percent). This work requires the electrician's full attention (2 percent). The compartment temporary lighting intensity is less than 75 foot-candles (2 percent) and there is a constant, rather loud noise present (1 percent). The work will require more than 2.5 minutes to complete (0 percent). Adjacent operations require the electrician to wear a filter mask (5 percent).

The fatigue allowance is the sum of the item allowances, or 15.45 percent.

UNAVOIDABLE DELAY

Many things can occur during the work day to interrupt a worker's progress, many of them beyond the control of the worker. Machines require scheduled or unexpected maintenance, material supplies run out, power failures occur, a foreman must talk to the employee, or machines may require resetting. These types of delays must be considered when developing allowances for a time standard.

To determine the allowances required for unavoidable delays, the analyst should perform either a work-sampling (ratio-delay) study or a time study. A work sampling study, where instantaneous observations are made at randomly selected times, is the most efficient as it requires less of the analyst's time, interferes less with production, may be combined with other like studies, and is as accurate as a time study. Delays that should be included are those which are clearly beyond the control of the worker and that can reasonably be expected to occur during a given work day. Operator-caused (avoidable) delays should not be considered as allowances. Social calls, excessive gauging or counting of work pieces, starting late, quitting early, excessive personal time, or rework due to poor workmanship are not allowable parts of the work cycle. Delays that occur regularly or predictably, such as changing or sharpening tools after a fixed number of cuts or obtaining and disposing of a container of parts should be prorated

into the normal cycle time instead of the delay allowances (5).

Close trade coordination is required as an electrician holds an equipment template for a service welder (2 percent).

BALANCING (MACHINE) DELAY

Delays are common when a worker must move from one station to another to complete a work cycle. As the number of work stations increases, so do the delays encountered. The amount of delay depends on the number of facilities assigned, the randomness of the moves, the ratio of servicing time to running time, the length of running time, and the average length of servicing time (3). Delays are encountered when the worker must wait for another worker to complete an assignment on the same machine, for repairs to be performed on a machine, for cleaning and oiling a machine, or to gather and return tools.

To develop the allowance for balancing (machine) delay, the work can be observed through a time study or a work-sampling (ratio-delay) study. The analyst must determine which of these techniques is the most practical for the application. These delays should be prorated into the normal cycle time, rather than into the allowances, if they occur consistently.

COMPLEXITY OF WORK

There is no precise way to measure the magnitude of work complexity. In operations where there is a large amount of repetition over a short cycle, there is rarely a need to compensate for complexity. Workers tend to become automated in their tasks and the learning time is so short that it may be negligible. Where an operation with a long cycle time requires the assembly of many parts of different sizes and shapes, as in ship work, the learning time may be long. Performing these kinds of tasks never becomes fully automatic and the assignment may be completed before full productivity is attained. Repetition on these jobs is low and the memory requirement is high. This allowance should not be confused with mental fatigue, which is the slowing of production due to stress. Complexity allowances are made to compensate for the time required to perform the mental 'processes.

To properly allow for complexity of work, the analyst must consider the

required degree of mental activity and the duration of the work cycle. Thinking and deciding, reading instructions, and referring to a model all require thought on the part of the operator. The number of repetitions of the work cycle, the duration of the job, and the employee turnover rate determine the learning exposure the employee has.

In activities such as ship repair, a good approach is to generally study all plant operations and develop a normalizing factor, which is a weighted average considering the pace of personnel and the performance of equipment. This normalizing factor is then applied to the normal time before the PF&D allowance. This normalizing factor is developed only once for the entire plant and is applied universally to all operations. This approach is especially useful when motion-time analysis or standard data is used to develop the normal time for low-repetition operations, such as those dealing with repair work.

SPECIAL ALLOWANCES

Special allowances are those that fit into no specific category but must be applied to arrive at a fair standard. Typical examples of these allowances are mustering of personnel at shift changes, clean-up of the work site, and other odd items that cannot be defined as personal, fatigue, and delay or be prorated into the normal time. The analyst can time study each special allowance item or observe them by work sampling. Some organizations have time set aside for these operations, either formally or informally. The analyst should check policies regarding special allowances before applying them.

Example:

An electrician is required to report to a five-minute muster four times a day for a total of 20 minutes (4 percent). Work site cleanup requires 10 minutes per day (2 percent). The total of special allowances is 6 percent.

APPLYING ALLOWANCES

After the analyst has determined all of the personal, fatigue, and delay elements, he must apply them to the normal time. This is done by developing a multiplier for an eight-hour day.

The example allowances are expressed as percentages of the shift. They must be summed (37.45 percent) and applied to the formula:

$$AF = \frac{100}{(100 - p)} \quad (1)$$

where:

AF = allowance factor, and

p = total of element percentages

Example :

$$AF = \frac{100}{(100 - 37.45)} \quad (2)$$

$$AF = 1.60$$

If the allowance5 are expressed in minutes (179.76). the formula is:

$$AF = \frac{480}{(480 - m)} \quad (3)$$

where:

AF = allowance factor, and

m = total of element times in minutes

Example:

$$AF = \frac{480}{(480 - 179.761)} \quad (4)$$

$$AF = 1.60$$

The normal time is then multiplied by the allowance factor to yield the true standard time.

Example: The analyst has determined that the normal operation time is 0.75 manhours. The actual standard manhour allowance is calculated as follows:

$$0.75 \text{ M/H} \times 1.60 \text{ (AF)} = 1.2 \text{ M/H} \quad (5)$$

SUMMARY

Allowances for the non-work elements in a work cycle are an important part of a time standard. These allowances should not be used as a 'dumping ground' for missed elements, but as a fair accounting of the non-productive elements which are part of a typical work day. Job conditions must be observed and analyzed to determine the true conditions and which allowances apply to the work cycle. The analyst should use the study as an opportunity to seek method improvements which will eliminate work delays and fatigue factors. The methods used must be consistent and objective. Work measurement techniques such as time

study or work-sampling should be used to determine the actual duration of the PF&D elements. Due to varied interpretations by work analysts (1), organizations should establish policies and standardized allowances. They may be itemized or simply blanket allowances, but all conditions must be considered. The penalty for ignoring PF&D is always a higher-than-predicted product cost which can quickly become lost business.

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Shipyard Trade Skill Testing Program

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IXB-2

The eight naval shipyard, in conjunction with the Naval Sea Systems Command have developed a system of written and performance tests applicable to journeymen level production workers. These tests were developed in compliance with the government's Uniform Guidelines on Selection Procedures and submitted to the U.S. Office of Personnel Management for approval. Four specific applications are envisioned for the tests: (1) Promotion of worker-grade personnel to journeyman positions; (2) Hiring experienced personnel from outside the federal government; (3) Identification of requirements for either additional or remedial training of apprentices; and (4) Identification of deficiencies in personnel training programs. Growth plans for the programs include progress test for apprentice programs, measurement associated with qualifications on new procedures, and certification in lieu of training on certain repetitive programs.

Tests have been developed for seventeen trades and validated by trial administrations at each of the naval ship yards. As part of the development process a task analysis was performed for each of the trades. Computer programs used for test generation allow the test designer to specify which tasks are to be measured in any given test and allow the tests to accommodate differences in job content and procedures at the several locations. Scoring and analysis features are also included in the computerized testing programs.

The task analysis and the computer programs are in the public domain. As such they can be made available to commercial shipyards with potential testing applications.

NOMENCLATURE

The following acronyms and abbreviations are used in this paper.

NAVSEA	Naval Sea Systems Command Headquarters
NAVSHIPYD SJOSE	San Jose Naval Shipyard

SSTS	Shipyard Skills-Tracking System
TSD	Trade-Skill Designator
USTIS	Uniform Shipyard Training Information System
SD	Supervisor's Desk
OPM	u. s. office of Personnel Management
FPM 335-1	Federal Personnel Manual Supplement 335-1
OCPM	Department of the Navy Office of Civilian Personnel Management

INTRODUCTION

The Naval Sea Systems Command Headquarters (NAVSEA) is working with the eight naval shipyards to develop batteries of written and performance tests that can be used to measure production worker's capabilities of accomplishing assigned shipwork. The tests are intended to help shipyards to assign the right personnel to complex jobs; to determine the best sections within each trade to assign newly-hired personnel; to determine what specialized training trade personnel require; to assess the efficacy of trade training programs; and, upon approval by the U.S. Office of Personnel Management (OPM), to make informed decisions in selection and promotion of trade personnel.

SCENARIO

The scene is just a short time from now at the (fictitious) San Jose Naval Shipyard (NAVSHIPYD SJOSE). A project team has just assembled at its

production worksite to prepare to accomplish its first assigned job on an SSN-688-class submarine refueling overhaul. The members have been selected because the automated Shipyard Skills-Tracking System (SSTS) [already in operation in seven of the eight real naval shipyards] has shown that they possess the appropriate Trade-Skill Designators (TSDs) [under active development in the real world] and that they possess the requisite formal qualifications to perform a number of the tasks their assigned job will entail.

Despite their qualifications, however, this job will involve accomplishment of a number of tasks that none of them has ever performed; some of these tasks are so sensitive to error (and improper performance would be so expensive to correct) that the team-and the shipyard-need to be absolutely certain that those who perform them are fully competent to do so. In addition, none of the team members has ever worked a job before following the precepts of zone technology, nor have any of them worked outside the boundaries of the specific trades in which they were trained. Working in this manner will entail a significant cultural change for them.

a. Having rounded up and reviewed all of the required technical documentation for the job, the team begins to parcel out work assignments to its individual team members. Willie, the team leader says to Joe, an electronics mechanic: "Joe, you clearly have the best background to perform Task 03.4. And the job will be performed most efficiently if you also perform associated tasks 03.3 and 03.5. But you've never performed those specific tasks before. So here's what we're going to do."

b. Willie turns to a video work station that has been brought to the worksite. When she touches the screen, a menu pops up. From the menu, she selects "enter task assignments." Following the directions on the screen, she enters Joe's badge number and task numbers 03.3, 4, and 5. From a menu, she then selects "task training and testing" and selects task number 03.3 as the starting point. Turning back to Joe, she says "Go for it!"

c. Joe sits down at the work station, which contains a microcomputer containing a 702-megabyte hard drive capable of storing, digitally, as many as 72 minutes of full-motion video (or combinations of motion video, still video, computer graphics, and text). Upon pressing the "enter" key, he is administered a brief pre-test of what he knows about how to perform task 03.3. The pre-test reveals that, while Joe is well-versed in most aspects of the task, he is unfamiliar with a couple of the specifications he must meet in accomplishing the task

d. To assure that Joe will have the requisite knowledge to perform task 03.3, the video/computer system administers a tutorial to him on the

knowledge requirements of task 03.3, with test questions built into the lesson. Joe views the lesson, answering the questions as they come up by touching the choices listed on the screen. When he picks a wrong answer, the system sends him back to review the part of the lesson containing the material he failed to master. If Joe misses the right answer to the same test question a second time, he is sent back to review the problem material once again-but this time, the content is presented to him in a different way, on the assumption that there was something about its presentation the first two times that didn't fit Joe's learning style. If the test question measures knowledge that is essential to correct performance of task 03.3, Joe is not permitted to progress through the lesson until he has demonstrated that he has acquired that knowledge

e. Once having completed the lesson for task 03.3, the interactive-multimedia system--for that, in fact, is the current name for the kind of system Joe is training on--moves Joe into a pre-test for task 03.4. Because the shipboard system on which Joe will be working is so sensitive to error, it is essential that task 03.4 be performed correctly in every detail; the passing grade for the lesson on task 03.4 is therefore set at 100 percent. Joe, however, is experienced at performing the task and answers all the questions in the lesson correctly the first time. The system therefore notifies the Shipyard Skills-Tracking System (SSTS) to update Joe's qualification records to show that he has requalified for task 03.4 as of this date, and it moves Joe into the lesson for task 03.5.

f. Task 03.5 is an installation process that requires performance of a number of work steps in a precise sequence. Joe is therefore shown a video of a mechanic performing the task; in the video, the key work steps are shown in slow motion and repeated several times, while the audio describes the steps being performed and why it is important that they be performed as shown. Joe is then tested by being shown a video of a mechanic performing the task at normal speed; Joe is asked to touch the screen if he sees a mistake being made. He is next required to walk through a simulation of the task, performing all of its worksteps, in sequence, by touching the objects shown on the screen at the appropriate times.

g. Joe successfully completes the simulation of task 03.5 and reports to his team leader. The team leader goes to the workstation, identifies herself to the system, and asks for a report on Joe's performance. The system displays Joe's grades on the lessons for task 03.3, 03.4, and 03.5, including, if the team leader asks for it, how many attempts Joe required on each question or each lesson before passing it. Satisfied that Joe is fully prepared to accomplish the three tasks, the team leader directs Joe to begin work.

h. When Joe gets to task 03.5, he wants to make sure he performs its complicated work steps in the

sequence demanded. He turns to the work station and calls up the task. He then watches the mechanic on the screen perform each step; puts the system on “pause”; mimics on the real ship component what he has just seen; restarts the system and repeats the process with each succeeding work step, thereby ensuring that he has left nothing to memory or chance.

i. Upon completion of the three task (and of any post-performance inspections required), Joe inserts his badge into a slot in the work station. This causes real-time work-status updates in Supervisor’s Desk [currently under development in the real world] and in the shipyard’s central management-information system modules; it also further updates Joe’s qualification and experience records in SSTS and his training records in the Uniform Shipyard Training Information System(USTIS) [another system that is currently under development].

DISCUSSION

The foregoing scenario describes how “just-in time”delivery of training could work in a shipyard. Some of the dividends shipyards would reap are obvious, such as virtual elimination of the problem of mental retention of knowledge and skills imparted through training. Other benefits might not be as readily apparent, such as the fact that the blurring of the distinction between training, on the one hand, and job preparation and performance, on the other, will likely make it possible for much of this training to be charged directly to ship customers, rather than to overhead.

Testing plays an intimate and prominent role in this kind of training. Testing is integral to the process of preparing personnel to accomplish ship repair work and to determining the relative competencies of those available to dot he work The repair of modern naval ships and submarines has become so sophisticated, and the consequences of error so significant, that to leaving to chance the capabilities of those performing ship repairs and alterations.is not acceptable NAVSEA through its Trade-Skill Testing Program is therefore making available to the naval shipyards validated written and performance

tests to assess the job proficiency of its wage-grade workers in these skilled trades. Occupational tests- i.e., tests that assess whether those tested are capable of performing as journeyman mechanics in their respective trades--have been issued for use in the promotion, selection, placement, and training of shipyard employees in **17** major skilled trades. The tests may not be used in promotions or in selection of applicants from outside the testing shipyard without the tests having first been approved for these uses by OPM, a process that is underway.] The li’ trades covered are shown in figure **1**.

A Trade-Skill Testing Program Users’ Manual has been issued to the naval shipyards. It contains guidelines that are designed to be consistent with current federal and Navy regulations governing the selection and promotion of employees, such as FPM 335-I. It should be emphasized that these are guidelines, not mandatory requirements. Naval shipyards have the option of deviating from the guidelines as long as their deviations are consistent with current Navy and federal personnel regulations. A companion manual, the Examiner’s Manual, provides detailed instructions for administering and scoring of the tests.

The trade-skill tests have been validated under the requirements of FPM 335-l and have been.ap- proved by NAVSEA for use in the naval shipyards under delegated authority from Navy’s Office of Civilian Personnel Management (OCPM).

The occupational examinations may be used in the following ways:

- 1. To promote current shipyard workers (apprentices and “limited” workers) to journeyman-level jobs.
- 2. To select and place external applicants with trade experience in journeyman-level jobs.
- 3. To determine the training needs of the pre sent workforce.
- 4. To evaluate the effectiveness of apprentice and other training programs.

It is important to note that NAVSEA has laid down the policy that the tests are not to be used for adverse personnel actions, such as firing and demo- tions.

Air-conditioning Equipment Mechanic	Boilermaker
Electrician	Electronics Mechanic
Electroplater	Fabric Worker
Insulator	Inside Machinist
Ordnance Equipment Mechanic	Outside Machinist
Painter	Pipefitter
Rigger	Sheetmetal Mechanic
Shipfitter	Shipwright
Welder	

Figure 1. The 17 trades for which occupational tests have been developed.

NATURE OF THE TESTS

The set of tests for each trade consists of a multiple-choice written examination and a "hands-on" performance test. This was done, in part, because the U.S. Office of Personnel Management will not permit use of written examinations alone in selection and promotion actions. (This policy stems from evidence that written tests, when used alone, may have an adverse impact upon socio-economically disadvantaged applicants)

The written tests in each trade consist of 100 to 150 multiple-choice questions that assess trade knowledge and ability to apply such knowledge. The tests take approximately two hours each to administer.

The performance, or practical, tests measure job skills, using actual tools and equipment of the trade. The performance tests take approximately one to four hours to administer.

DEVELOPMENT OF THE TESTS

Professional test designers were hired to shepherd development of the tests. This was done to ensure that the tests maintained both face validity and content validity; that every test item would be validated against essential job requirements; and that the tests met the standards of the federal government's Uniform Guidelines on Employee Selection Procedures. This kind of rigor was necessary to the securing of OPM approval of the tests and to precluding grievances and litigation. If grievances or litigation against the tests should occur, the tests can be defended on the basis that they measure knowledge and skills that are essential to competent job performance.

The tests were developed by panels of representatives of the 17 trades, guided by the professional test designers. As part of the development process, a task analysis was performed for each of the trades. This analysis divided the trade into several major duties; identified tasks within the duties; and identified the knowledge and skills required for a worker to perform each task competently at the journeyman level. (The task analyses were designed to accommodate differences in procedures and job content within the same trade among the eight naval shipyards.)

Each of the written test items is tied to the task analysis and has also been referenced, wherever possible, to applicable technical specifications.

Once written, the test items were loaded into a computerized test-item data bank. Computer programs have been written that enable semi-automated test generation: the test designer has merely to specify which task are to be measured in a given test,

and the computer assembles appropriate test items into a new test. Other computer programs include automated test analysis and scoring of test answer sheets.

All of the tests were administered on a trial basis to journeymen at the naval shipyards and were revised to ensure that they are reliable, fair, and valid measures of trade-skill and knowledge.

CONCLUSION

Following implementation of the initial 17 occupational trade-skill tests, NAVSEA plans to begin development of two additional kinds of tests:

Progress Tests

Progress tests will be developed to be administered to apprentices every six months, as they become eligible for their semiannual promotions. These tests will give shipyards a clearer picture of the efficacy of their apprentice training programs and should also serve to spur production shops toward greater conscientiousness in managing the rotation of apprentices among the skills of their trades.

Specialized Tests

Specialized tests in advanced technical skills will be developed. Examples of such tests include tests of mechanics' ability to perform jobs never before accomplished at a particular shipyard; tests of ability to perform the work involved in a complex ship alteration (ShipAlt); and tests of competence on jobs that have been generating rework; and, of course, tests to be integrated into the fabric of interactive work qualification and assignment process described in the scenario that opened this paper.

ACKNOWLEDGEMENT

The author was assisted in the preparation of this paper by Lieutenant Commander C. Lee Walker, USN (Retired).

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A Summary Report: A Survey of The Principal Elements of Safety Programs at Nine American Shipyards

IXB-3

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ABSTRACT

The Survey, which is the subject of National Shipbuilding Research Program (NSRP) Publication #0318 and of this paper, was sponsored by Panel SP-5, Human Resource Innovation. It was designed to collect a significant amount of detailed information concerning the principal elements of safety programs currently in effect in major American shipyards so as to:

identify the core elements common to all or most of such safety programs:

identify the managerial philosophies that underlie such programs:

- provide base line information so that participating yards and others in the industry can make comparisons and evaluations of their own safety programs; and
- bring about an awareness throughout the industry of new initiatives that have been tried and found successful in one or another shipyard and an awareness of experiments which are taking place with new and/or changed technologies designed to have a positive influence on safety program goals.

The ultimate objective of the project is to prevent occupational injuries and illnesses and thereby avoid their costs, including medical, workers' compensation and lost production costs.

BACKGROUND

There is general acceptance of the observation that each shipyard in the industry has its own personality. That personality is the product of many factors including the yard's history, its size, its organizational structure, its employee relations atmosphere and its management style. It is dynamic, not static, and adjusts to internal and external influences. Each yard, therefore, develops and implements its policies and procedures, including those governing occupational safety and health matters, in a manner that suits its personality. Although external influences may

have contributed to the development of a particular yard's safety program and elements thereof (for example, the U.S. Navy's influence on safety programs in the public shipyards), the extent to which and manner in which those influences are made manifest are affected by the yard's personality. It has often been said that what works in one yard may not work in another. Each yard is the best judge of what will work for it.

In full recognition of the above, attempts have been made over the years to gather, at a central source, safety program information from the yards in the industry so that individual yards could examine what others were doing, make their own **evaluation** of the applicability and efficacy of the data, and thereby enhance their self evaluation process. However, to the best of Panel SP-5's knowledge, no really satisfactory collection of such data had heretofore been accomplished.

Because of the competitive nature of the firms in the industry and the historic arms-length relationships that have developed among and between them in sensitive areas that affect the bottom line, there historically has been limited formal exchange of detailed information as to the principal elements of safety programs. That is not to say, however, that the shipyard experts in safety and health matters do not meet from time to time to exchange information. On the contrary, information is exchanged in regional and national meetings of the National Safety Congress, and in regular meetings of the Health and Safety Committee of Shipbuilders Council of America, to name but two.

Exchanges of such information between private and public shipyards, however, have been virtually non-existent. Indeed, public shipyards are not members of Shipbuilders Council of America.

Further, the kind of information that has been exchanged, and that has been made available through the National Safety Congress, the Department of Labor and others, usually deals with the measurements of performance in certain narrowly defined fields like lost work day and lost work cases incidence rates, expressed as a factor of numbers of manhours worked. The exchanges of data and the publication of data rarely go to the factors that affect the environment in which those statistics are created.

THE SURVEY DOCUMENT

Panel SP-5 recognized that because of its human resource concentration and its diverse membership, it was in a unique position to accomplish the data accumulation that had for so long been elusive.

The Panel established an ad hoc committee whose function was to design a survey document that would achieve the objectives set forth above under the abstract of this paper. That committee sought from the Panel's member yards a list of suggested questions to be included in the survey document. Exercising the expertise in safety program design possessed by the individual ad hoc committee members it created the survey document drawing from a list of questions submitted by Bethlehem Steel/Sparrows Point, General Dynamics-Electric Boat and Norfolk and Puget Sound Naval Shipyards in response to its request.

In a presentation made during the Third National Workshop on Human Resource Innovation on October 16, 1991, Joseph Collier, Director of the Office of Consultation Programs for the Occupational Safety and Health Administration, discussed the central core requirements which underlie the safety and health management aspects of OSHA's Voluntary Protection Programs (VPPs). Those core requirements are expressed in what is called a "Guideline" on safety and health management that has been published in the Federal Register. It is a voluntary guideline in the sense that it is not a standard that OSHA requires companies to follow, but one that it recommends be followed. The four basic guidelines are:

- Management commitment and employee involvement;
- Worksite analysis;
- Hazard prevention and control; and
- Safety and health training.

Of primary importance in any safety and health program is a policy statement making clear the company's commitment to safety: that safety is as important as production. Employee involvement includes labor-management committees that are meaningful and active and get the employees involved in the structures, operations and decisions affecting their safety and health. Assignment and communication of responsibility is important so that everybody in the workplace knows what is expected of him or her and understands what he or she is expected to do so there is no confusion or overlap. Along with the assignment and communication of responsibility is the giving of adequate authority and resources to carry out that responsibility. There must also be a system for all managers, supervisors and employees to be held accountable for what they have been assigned to do.

That involves rewards and corrections.

The second major factor is worksite analysis, involving, first of all, comprehensive surveys to set a baseline of data about what kinds of hazards are present in the workplace. Another critical part of the effort is that whenever change is to be made in the facilities, equipment, materials or processes of the site, safety and health issues are taken into account. Safety and health people should be involved with the architects and engineers and others who are planning the manufacturing process or the assembly process to take into account, up front, the hazards that might be put into place by these changes, and to be sure that there are preventions or protections for them. Also included in worksite analysis is routine hazard analysis, including phase hazard analysis in situations when one moves from one place to another. Finally, provisions should be made for routine, regular safety and health inspections and reliable systems for employees to report hazards: participation of employees and others in investigating accidents and near-misses; and analyzing patterns of injuries and illnesses and addressing them.

The third major factor is hazard prevention and engineering and administrative controls. Preventive maintenance is also included, to be sure that machinery does not become hazardous because of breaking down or whatever, and finally, emergency planning and a medical program.

And then, under safety and health training, the key concerns are (1) that employees understand the hazards to which they and their fellow employees are exposed and understand their role in preventing anyone from being hurt because of the hazards, (2) that supervisors understand their responsibilities to identify and correct hazards, to maintain the physical protections that are placed in their work areas, to reinforce employee training through feedback, and to enforce rules, and (3) that managers understand their role in the process of safety and health.

The survey document covers each of the items in those Guidelines in depth. It contains eighty-five distinct questions many of which have multiple parts and many others of which called for essay type responses. Indeed, it is estimated that a typical participating shipyard responded to well over 300 questions in the body of the survey document and to twelve additional multiple part questions in the Appendix concerning Safety Training Programs.

YARDS INCLUDED IN THE SURVEY

The following twelve shipyards, eight private and four public, were asked to participate in the survey:

Avondale
Bath Iron Works
Bethlehem Steel/Sparrows Point
General Dynamics-Electric Boat
Ingalls

Mare Island Naval Shipyard
 NASSCO
 Newport News
 Norfolk Naval Shipyard
 Norshipco
 Philadelphia Naval Shipyard
 Puget Sound Naval Shipyard

Each yard was advised that, in order to maintain anonymity, individual shipyards would not be identified in the report. Where specific reference was necessary or desirable, an individual shipyard would be referred to by an arbitrarily assigned number.

Initially, all twelve shipyards agreed to participate and, upon invitation, each of them was visited by the author for the purpose of reviewing the survey document, in a face-to-face setting, prior to final completion and return. Three of the twelve shipyards, two private and one public, without notification or explanation, failed to return a completed questionnaire. The report, therefore, contains the responses of those nine shipyards. They comprise an excellent and representative cross section of the United States shipbuilding industry.

THE SURVEY

When responses to the survey document were received, recorded and compiled, a draft report was sent to each participating yard requesting that it check the accuracy of the data reported for it. After a second exchange of comparisons a meeting was held to provide all participating yards the opportunity to review and compare responses and to discuss safety and health matters beyond the scope of the Survey itself in advance of the publication of the report. That meeting has been referred to as the New Orleans meeting.

It is impossible in a Paper of this nature to comment on the data as a whole (because of the mass of it) or even to select the most important for comment because each piece of data is an integral part of the whole just as each piece of a safety program is an integral part of the total program. As a reminder, there were eighty-five distinct questions, many with subsets, covering every conceivable aspect of a shipyard safety and health program.

Nevertheless, at the conclusion of the New Orleans meeting the shipyard representatives at that meeting engaged in an interesting exercise of prioritizing the elements of safety programs, using as a rough guide a shorthand version of the eighty-five distinct questions in the survey document. The object was to place, by consensus, the elements into one of the following three groups:

Group 1- Basic Core Elements

Group 2 - Elements essential to be a complete safety program (Enhancements of Basic Core

Elements): or

Group 3 - Complementary elements to those considered essential but to a lesser extent than those in Group 2.

When consensus was achieved as to which elements belonged in which Group, participants then prioritized the elements within groups. An element rated (1) was given the highest priority, (2) the next highest and so on. Those elements which the attendees agreed belonged in Group 1 and the order in which they ranked them are as follows:

- (1) Top Management maintains active involvement on a daily basis in safety and health matters.
- (2) Safety and health are integrated into daily operations.
- (3) Supervisors are held accountable for safety and health.
- (3a) Safety and health performance is daily responsibility of line supervision.
- (4) Safety and health are incorporated in other shipyard policies.
- (4a) Overall safety and health responsibility is fixed in shipyard.
- (4b) Primary responsibility for safety and health is fixed.
- (5) Shipyard has adequate medical treatment for injured employees.
- (6) Discipline is used for noncompliance with safety and health standards.
- (7) All shipyard employees receive initial safety and health training.
- (8) Shipyard has a safety and health policy.
- (8a) Safety and health decisions are consistent with overall shipyard goals.
- (9) Supervisors are rewarded (positive or negative) for safety and health performance.
- (9a) Supervisors are frequently apprised of safety and health performance.
- (9b) Safety and health standards are communicated to line supervision.
- (9c) Supervisor's safety and health performance is measured.
- (9d) Shipyard has other adequate systems to measure safety and health performance.

- (10) Comprehensive accident investigation takes place with follow-up.
- (11) Safety and health performance data is on agenda of management meetings.
- (12) Employee protection is afforded through engineering, administrative controls and personal protective equipment.
- (13) Safety and Health Director is adequately placed in shipyard organization.
- (14) Managers/Supervisors can stop unsafe work.

Again it should be noted how precisely this prioritization parses with the Guidelines cited by OSHA's Mr. Collier referred to earlier.

The Survey Report also commented on the importance of top management's commitment. It observed that in order for any safety program to be effective it must be reflective of, and be guided by, the organization's philosophy and policy in occupational safety and health (OSH) matters. That policy must be known to, and clearly understood by, all members of the organization. There is no room in an effective safety program for ambiguity in top management's dedication of purpose. A formal written statement setting forth an organization's guiding principles, its objectives and its policy to achieve those objectives is a first step in eliminating ambiguity. The larger the organization the greater the difficulty in informing and educating the members, hence, the greater need for committing the policy to writing. The fact that the organization is willing to commit its policy to writing in and of itself sends a message of its sincerity.

While the lack of a written statement of policy, all other things being equal, would not invalidate an otherwise sound safety program that absence would be conspicuous to those inside and outside of the organization and would send an improper or, at best, ambiguous message which, as noted above, is to be avoided at all costs.

Eight of the yards submitted statements of safety policy in the form either of policy as part of its formal Safety Program or of a stand alone document such as a letter from the Chief Executive Officer to all employees or a Memorandum of Policy. As might be expected those statements of policy varied in degree of elaboration from the very complete to the more concise. The following is an example which contains the essential elements reflected in all of them.

"It is the policy of [yard] to establish and maintain a comprehensive Occupational Safety and Health Program which is based on the following principles:

- a. Our people are our greatest asset.

- b. Safety is an inseparable part of all shipyard operations, and will be appropriately integrated into all work and training activities.
- c. All occupational injuries and illnesses can be prevented through recognition and prevention of hazards. Our goal is continuous long term improvement in injury/illness prevention.
- d. We will comply with the OSH regulations which are applicable to our operations.
- e. All employees must be involved in recognizing and preventing hazards, and complying with OSH requirements applicable to their work.
- f. Managers and supervisors at all levels are responsible for the safety of the people and operations within their areas of responsibility.
- g. Planning/technical personnel are responsible for determining OSH hazards and requirements associated with planned operations, and for incorporating appropriate OSH provisions into plans and procedures for accomplishing the work.
- h. We will establish systems to objectively measure our progress in achieving long term improvement."

An example of a more concise statement is as follows:

"It is the policy of this Shipyard that all employees will be provided with a safe and healthful work environment, which is free from recognized hazards and consistent with current federal, state and local standards."

All yards indicated that safety and health considerations were integrated into functional procedures affecting operations throughout the shipyard. Examples of some of the responses follow:

- "All policies are subject to a Safety First condition."
- "Occupational Safety and Health is included in the guiding principles of the shipyard's Total Quality Management program."
- "The performance of [shipyard] is measured by only one set of criteria-whether or not we perform quality work on schedule, at low cost in a safe manner."

Most yards also indicated that at their operation ultimate responsibility for overall safety and health performance rests at the top of the organization. The yards were unanimous in their view that, contrary to the belief held in some circles, ultimate responsibility does

not rest in the Safety Office.

Recognizing that the causes of all accidents fall into two basic categories-unsafe conditions and unsafe acts-it is generally held that management is responsible for providing safe working conditions and employees are responsible for acting in a safe manner. Beyond those considerations it is generally acknowledged that management has a responsibility to ensure that employees are aware that certain acts are unsafe and are aware of ways to avoid them. Management fulfills that responsibility by providing formal and informal training, both on-the-job and in classroom: it ensures that first and second line supervisors are similarly aware and it holds those supervisors accountable for their own safety and health performance and the safety and health performance of the employees under their supervision. Management also imposes discipline on employees and supervisors who perform unsafe acts and supervisors who tolerate or condone the performance of unsafe acts.

While all of the yards indicated that they review their supervisors' safety and health performance, the time periods for such performance reviews vary considerably. All yards do, however, apprise supervisors of their performance whenever it varies from an acceptable standard and also, at all yards, that standard has been made known to supervision.

The Survey revealed that the qualifications of safety personnel are governed by written standards at each operation and are not merely a reflection of the qualifications of the employees currently filling the billets.

The ratio of full time safety and health personnel to "blue collar" worker varied from one per 210 to one per 670 with an average for the nine yards of one per 470. No conclusion should be drawn from the different ratios. However, the ratio is a factor at least in training and other administrative areas which bear on the safety program and in specific areas of emphasis. On the other hand, a higher ratio may reflect that some safety responsibilities have been shifted to others.

Questions with respect to personal protective equipment (PPE) elicited some unexpected results. In the public shipyards employees do not pay the cost of any PPE required to be worn: in the private shipyards practices vary from yard to yard, and the Survey indicates for each private yard which items of PPE are furnished at no cost to the employees and of which the employees must pay all or a portion of the cost.

Seven of the nine yards responded to the question "What is your annual personal protective equipment cost per employee?" The responses ranged from a low of \$83 to a high of \$430 with an average cost of \$217. One yard did not provide a dollar cost figure because its accounting practices did not readily identify such costs and the other yard, for its own reasons, chose not to provide them.

One would assume that the public yards, as a group, would have PPE costs significantly higher than those of the private shipyards. The fact is, however, that the public yards show a lower than average cost and the private shipyards show a greater than average cost, just the opposite of what one would expect.

At first reading it would appear that there is an inconsistency between requiring employees to buy certain of their own personal protective equipment and a claimed managerial dedication to safe working conditions and practices. The information does not, however, support a conclusion of such inconsistency. The information reflects historical customs and practices at the various yards. The point to be stressed here is that this information reflects different purchasing practices and not different required use practices. Where practices in the yards are similar in respect of mandatory use of certain items of personal protective equipment, it is really irrelevant from a safety and health standpoint whether the management provides it or the employees purchase their own-the amount of protection provided is the same.

CONCLUSION.

Perhaps the most important single element of any safety program is the dedication with which the organization implements and enforces its formal written statement of occupational safety and health policy. The antennae of the members of an organization are keenly sensitive to the parallelism between policy and its implementation. Deviations from parallel do not go undetected. Repeated deviations without adequate explanation force questions, verbalized or mute, as to whether the policy is both words and actions or words without action.

Top management's consistent active involvement in policy implementation as reflected in the safety program is crucial to the effectiveness of that program. The degree of its involvement is observed and evaluated on a daily basis by employees at every level in the organization. If employees at any level perceive that the organization's actual commitment is less than indicated in the statement of policy, that perception will govern their conduct and the program will suffer.

The consensus of the representatives at the New Orleans meeting was that the degree of top management commitment and involvement at the yards which participated in the Survey would range from some active personal involvement in some of the yards to significant active personal involvement in some others. It is questionable that any of the yards, save one, would compare favorably to a standard of strong active personal involvement. One yard's top management demonstrates outstanding personal involvement

bordering on zealotry. It was also the consensus that that is the standard against which all yards should be measured.

REFERENCES

- National Shipbuilding Research Program
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Programs' Guidelines.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

<http://www.nsnet.com/docctr/>

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